JUNE 1961

Journal

VOL. 53 • NO. 6

AMERICAN WATER WORKS ASSOCIATION

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AMERICAN WATER WORKS ASSOCIATION

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Journal AWWA is published monthly at Prince & Lemon Sts., Lancaster, Pa., by the Am. Water Works Assn., Inc., 2 Park Ave., New York 16, N.Y. Second-class postage paid at Lancaster, Pa. Authorized Aug. 6, 1918. $8.00 of members' dues are applied as a subscription to the JOURNAL; additional single copies—85 cents. Indexed annually in December; and regularly by *Industrial Arts Index* and *Engineering Index*. Microfilm edition (for JOURNAL subscribers only) by University Microfilms, Ann Arbor, Mich.

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Coming Meetings

AWWA SECTIONS

Spring 1961

Jun. 20–22—Pennsylvania Section, at Galen Hall Hotel, Wernersville. Secretary, L. S. Morgan, County Health Dept., 50 N. Main St., Doylestown.

Jun. 27—New Jersey Section, at North Jersey Country Club, Wayne. Secretary, A. F. Pleibel, Dist. Sales Mgr., R. D. Wood Co., 683 Prospect St., Maplewood.

Fall 1961

Sep. 11–13—Kentucky-Tennessee Section, at Brown Hotel, Louisville, Ky. Secretary, Harold F. Mount, Gen. Mgr., Preston Street Road Water Dist. No. 1, 5400 Preston Hwy., Louisville, Ky.

Sep. 13–14—New York Section, at Saranac Inn, Saranac Lake. Secretary, Kimball Blanchard, Neptune Meter Co., 2222 Jackson Ave., Long Island City 1.

Sep. 13–15—North Central Section, at Pick-Nicollet Hotel, Minneapolis, Minn. Secretary, Carl A. Flack, Registrar, Water Dept., 216 City Hall, St. Paul 2, Minn.

Sep. 20–22—South Dakota Section, at Sheraton-Johnson Hotel, Rapid City. Secretary, J. Darrel Bakken, Div. of San. Eng., State Dept. of Health, Pierre.

Sep. 25–26—Maritime Branch, Canadian Section, at Brunswick Hotel, Moncton, N.B. Secretary, J. D. Kline, Gen. Mgr., Public Service Com., Halifax, N.S.

Sep. 27–29—Wisconsin Section, at Hotel Schroeder, Milwaukee. Secretary, Harry Breimeister, Bureau of Engineers, Room 607 Municipal Bldg., 841 N. Broadway, Milwaukee.

Sep. 28—Connecticut Section. Secretary, D. W. Loiselle, Supt. of Supply, Bridgeport Hydraulic Co., 835 Main St., Bridgeport.

Oct. 1–3—Missouri Section, at Kentwood Arms Hotel, Springfield. Secretary, Warren A. Kramer, Chief, Water Supply, Div. of Health, State Office Bldg., Jefferson City.

Oct. 2–4—Rocky Mountain Section, at La Katchina Hotel, Taos, N.M. Secretary, H. F. Kepner, Vice-Pres., Dana Kepner Co., 550 Alcott, Denver, Colo.

Oct. 4–6—Virginia Section, at Hotel Roanoke, Roanoke. Secretary, Edward H. Ruehl, R. Stuart Royer & Assocs., 15 W. Cary St., Richmond 20.

Oct. 5–6—Intermountain Section, at Twin Falls, Idaho. Secretary, M. W. Snell, Supt., Power & Water, Soda Springs, Idaho.

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Coming Meetings

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Oct. 8–11—Alabama-Mississippi Section, at Buena Vista Hotel, Biloxi, Miss. Secretary, Ernest Bryan, Southern Sales Mgr., McWane Cast Iron Pipe Co., Box 2601, Birmingham, Ala.

Oct. 15–18—Southwest Section, at Granada Hotel, San Antonio, Tex. Secretary, L. A. Jackson, Mgr.-Engr., Municipal Water Works, Robinson Memorial Auditorium, Little Rock, Ark.

Oct. 18–20—Iowa Section, at Roosevelt Hotel, Cedar Rapids. Secretary, Wilbur E. Bjork, Service Supt., Des Moines Water Works, 1003 Locust St., Des Moines.

Oct. 25–27—California Section, at Hotel Senator, Sacramento. Secretary, Frank F. Watters, Hydr. Engr., State Public Utilities Com., State Bldg., Civic Center, San Francisco.

Oct. 25–27—Ohio Section, at Commodore Perry Hotel, Toledo. Secretary, J. H. Bass, Henry P. Thompson Co., 4866 Cooper Rd., Cincinnati.

Oct. 25–28—New Jersey Section, at Dennis Hotel, Atlantic City. Secretary, A. F. Pleibel, District Sales Mgr., R. D. Wood Co., 683 Prospect St., Maplewood.

Oct. 29–Nov. 1—Florida Section, at Cherry Plaza Hotel, Orlando. Secretary, John B. Miller, Director, Div. of Water Supply, Bureau of San. Eng., State Board of Health, Box 210, Jacksonville 1.

Nov. 1–3—Chesapeake Section, at Emerson Hotel, Baltimore, Md. Secretary, Carl J. Lauter, 6955—33rd St. N.W., Washington, D.C.

Nov. 13–15—North Carolina Section at George Vanderbilt Hotel, Asheville. Secretary, T. Z. Osborne, Asst. Director of Public Works, Greensboro.

OTHER ORGANIZATIONS

Jun. 18–23—AIEE, Ithaca, N.Y.

Jun. 26–Jul. 1—7th Congress, International Committee on Large Dams, Rome, Italy.

Jun. 25–30—ASTM Annual Meeting, Atlantic City, N.J.

Jul. 4–7—National Society of Professional Engineers, Olympic Hotel, Seattle, Wash.

SHORT COURSES

Jun. 19–21—Rudolfs Research Conference, Rutgers University, New Brunswick, N.J. Write: H. Heukelekian, Chairman, Dept. of Sanitation, Rutgers University, New Brunswick, N.J.

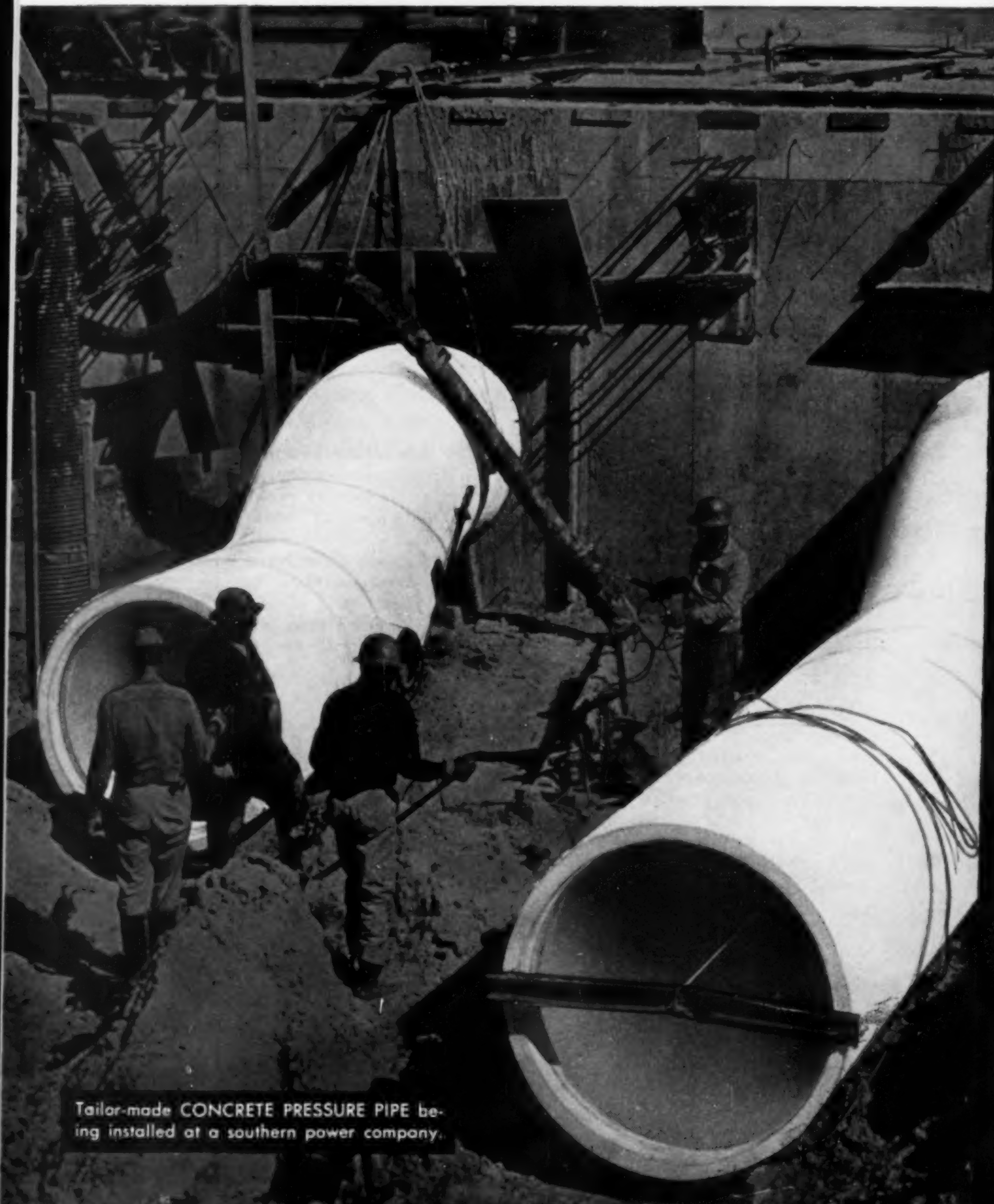
Jun. 19–30—Training Course on "Aquatic Biology for Engineers," Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. Write: Chief, Training Program, 4676 Columbia Pkwy., Cincinnati 26, Ohio (or to USPHS regional office).

Jul. 10–Sep. 9—Training course on "Engineering Aspects of Radiological Health," R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio. Write: Chief, Training Program, 4676 Columbia Pkwy., Cincinnati 26, Ohio (or to USPHS regional director).

Jul. 23–Aug. 4—10th Annual Utility Management Workshop, sponsored by Columbia Univ., at Arden House, Harriman, N.Y. Write: M. F. Garvey, 409 Engineering Bldg., Columbia Univ., New York 27, N.Y.

Jul. 24–28—Training course on "Recent Developments in Water Bacteriology," R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio. Write: Chief, Training Program, 4676 Columbia Pkwy., Cincinnati 26, Ohio (or to USPHS regional director).

Adaptable



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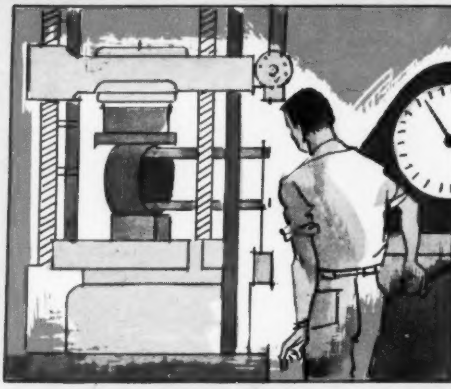

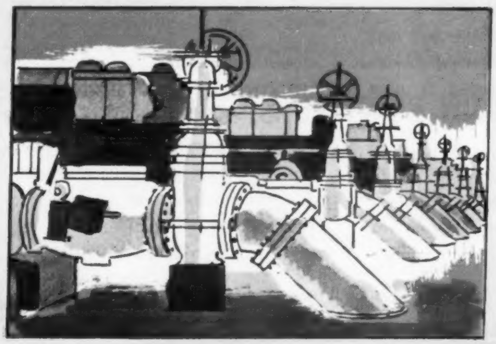

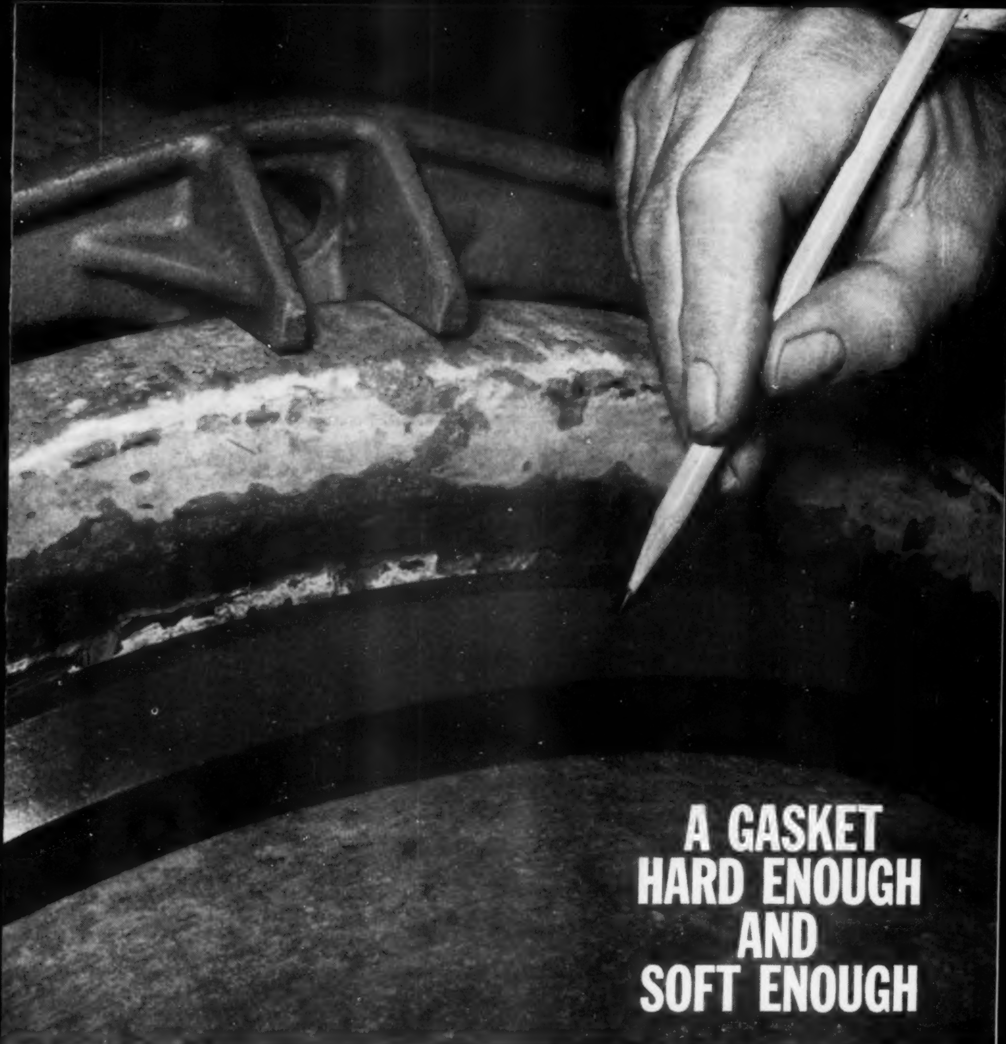

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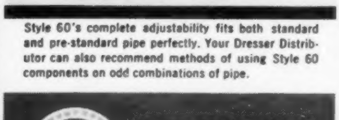

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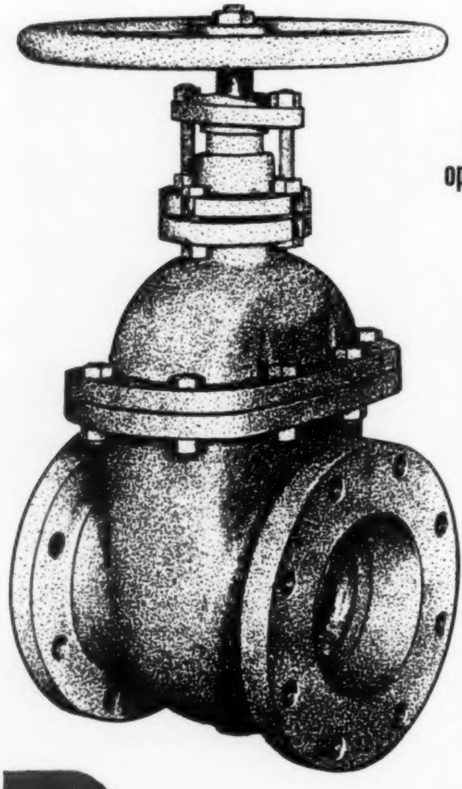

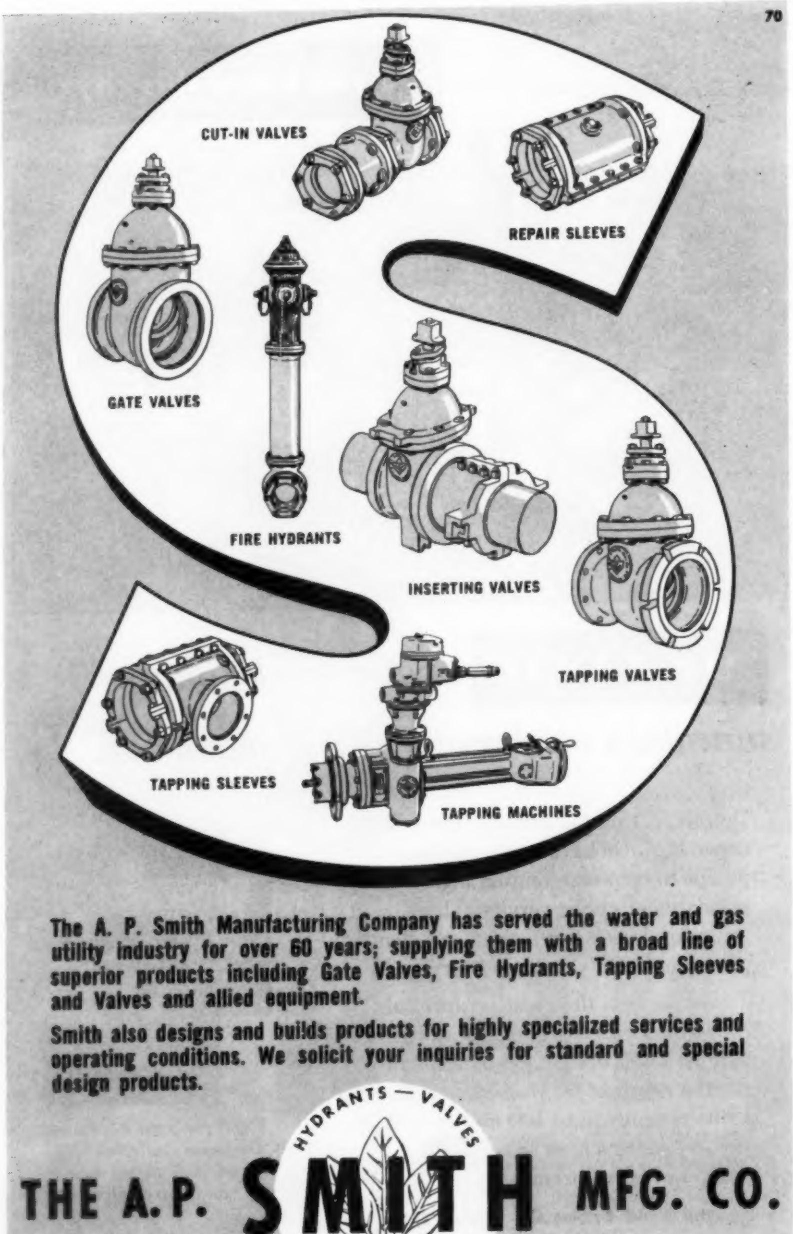
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Journal
AMERICAN WATER WORKS ASSOCIATION
VOL. 53 • JUNE 1961 • NO. 6

Use of Water Pipe as an Electric Ground

Joint Discussion

A joint discussion presented on Oct. 26, 1960, at the California Section Meeting, Long Beach, Calif.

Lee B. Hertzberg

Supervising Mechanical and Electrical Engineer, East Bay Municipal Utility District, Oakland, Calif.

FOR nearly a half-century, the water utilities have found themselves involved in work that is really the responsibility of the electric utilities, work that has no bearing on water safety, adequacy, or potability. Unwillingly and, in many cases, unwittingly, water utilities have been "drafted" by the electric industry to provide, through water piping systems, a part of the electric utility system—the ground connections to water pipe.

Although the use of this type of grounding is familiar, it seems advisable to review briefly the reasons advanced by the electric industry to justify such usage.

Reason for Grounding

In Fig. 1, a typical residence is shown with electric service supplied by overhead wires and water furnished through underground pipe. The electric utility has extended its high-voltage lines to a pole adjacent to the customer's property, installed a transformer to reduce the electrical pressure from transmission to distribution voltage, installed service wires from the transformer low-voltage terminals to the customer's service head, and installed the meter.

So far, this installation of electric service is comparable to the installation of a water service, through a pressure regulator, service tap, and meter, to the customer's service pipe. But here the comparison ends.

Electric overhead lines are subject to lightning strokes. Furthermore, a transformer will occasionally develop a short-circuit between primary and secondary windings. Either occurrence results in momentary high voltages on the electric service wires.

To protect its equipment from lightning damage, the electric utility bypasses the lightning stroke to ground through lightning arresters, which are

connected by grounding wires to a ground rod installed near the base of the transformer pole. The utility also connects a grounding wire from this ground rod to the center of the transformer low-voltage winding, so that the heavy current flow resulting from a short-circuit between windings will cause the substation fuses to blow, de-energizing the high-voltage line.

nect his ground wire to a ground rod or its equivalent. If a metallic water service pipe is available, the National Electrical Code [1] (NEC) requires the electricity customer to attach the ground wire to this pipe, as shown in Fig. 1.

The NEC preference for a water service pipe instead of a ground rod is based on the historical fact that when

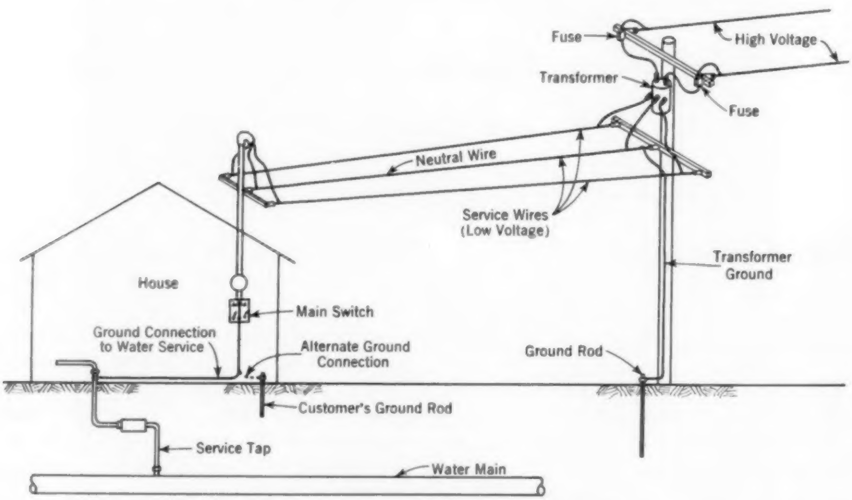

Fig. 1. Alternative Ground Connections

It is being recognized that electric ground connection to water pipe is unreliable. For continuous protection, the customer's electric service should be grounded to his own ground rod (dotted line).

These protective devices can fail to operate. Therefore, because any high voltage on service wires is carried inside the house, the electric industry makes the customer protect himself against such malfunctions. It requires that he connect all electric service equipment enclosures and his end of the neutral service wire to an adequate ground.

In the absence of a metallic water service pipe, the customer must con-

the electric industry decided 50 years ago that all a-c systems should be grounded for safety reasons, most water piping systems were metal. Mains were cast iron or riveted steel, services were copper, lead, or cast iron, and joints were lead calked, so that the entire water system was electrically continuous. In effect it formed one big ground rod.[2]

Furthermore, when leaks were repaired or pipe replaced, the same ma-

terials were used, so that the electrical character of the underground water system was unchanged. With such a ready-made ground rod available, the electric agencies naturally used it.

The electric industry based its use of water service pipe as electrical grounding on the following assumptions:

1. A metallic water service pipe is always proof of an electrically continuous metallic water system
2. Any repairs or replacements in the water system do not change its electrical characteristics
3. Electric currents flow in the water piping only momentarily during abnormal conditions.

All three assumptions have proved incorrect. Before showing how this is so, however, it would be well to review the actions of the water utilities regarding grounding.

Up to about 50 years ago, the National Electrical Code recommended grounding but did not require it. Following a study and recommendation by the AIEE, grounding for a-c distribution circuits was made a mandatory requirement of the National Electrical Code, starting with the edition published in 1913.

Early AWWA Policy

Soon, water system operators began to oppose any electrical connections between water pipe systems and electric distribution facilities.[3] With assurances from the electric industry that these grounding connections were the only practical means of protecting property and persons, however, and that such connections would not present any hazard, inconvenience, or difficulty to the water operators, and would not damage water pipe or impair quality, in 1920 AWWA approved a resolution sanctioning such grounding connections, if done as specified in the National Electrical Code.

By 1927, AWWA, after 14 years of experience with grounding, felt it necessary to limit its 1920 endorsement as follows[4]:

1. The AWWA approves the practice of grounding the secondaries of lighting transformers on water pipes for the purpose of safeguarding life and property, provided that appreciable electric current flows over such ground connections only during comparatively short and infrequent intervals when the ground connections are fulfilling their specific protective purposes, and provided that such ground connections impose no responsibility upon the pipe-owning company.

2. The AWWA is opposed to the use of water pipes as electrical conductors, except as noted above, and since experience with certain power distribution practices which have come into use has shown that grounding may result, and in many cases has resulted, in hazard to the pipe structures and water works employees, it hereby withdraws its former general endorsement of grounding on water pipes.

Policy Changes

It was hoped that the 1927 statement would settle the matter, but a few years later it reappeared in a different guise. At the Pacific Northwest Section Meeting in the spring of 1932, the grounding problem was defined, and various hazards to water utility personnel were described.[5] Then at AWWA's 1933 Annual Conference, a paper was presented entitled "Promiscuous Electrical Grounding on Water Service Pipes and Mains."[6] Included in this report was a short discussion of electrolysis. Several examples in which pipe corrosion, water discoloration, or taste and odor problems were apparently cleared by removal of various electrical grounding connections

were cited. The authors, while admitting that those examples were inconclusive, pointed out the need for further study. These two papers reopened the whole grounding question. scinds any and all previous approval or sanction of the practice of grounding electric light and power circuits on water pipes for protective or other purposes." [7]

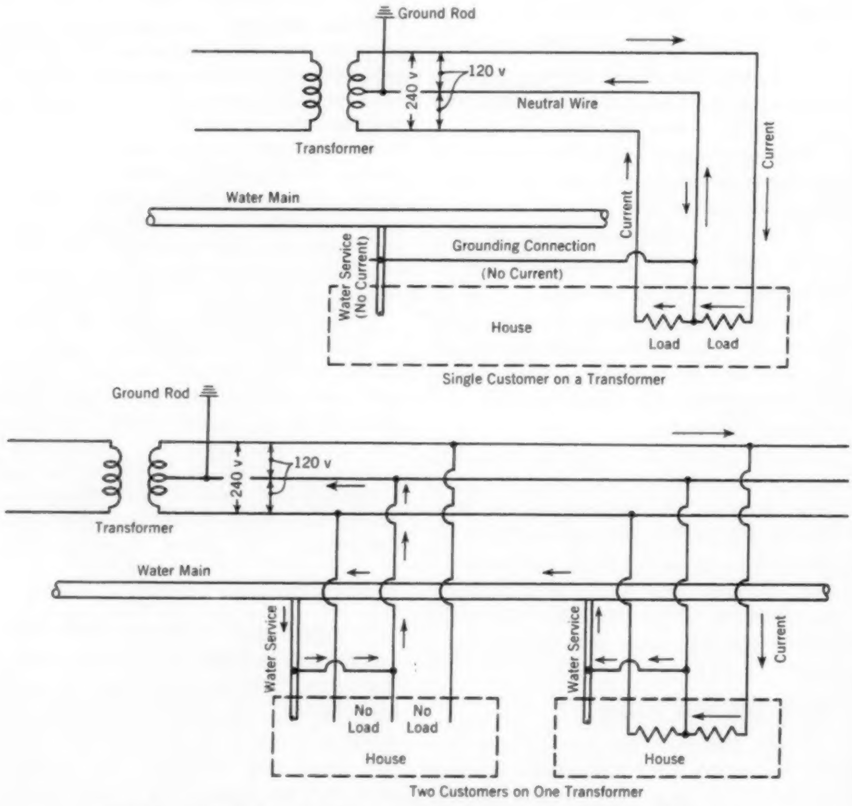

Fig. 2. Current Flow With Two Customers on One Transformer

With one customer on a transformer, current flows to water service and main only in unusual circumstances. With two customers on the same transformer, however, some current flows continuously through service pipe and main.

By 1935, AWWA seemed to feel that "isolationism" might be the answer, and attempted to withdraw from the grounding battle by adopting a resolution stating, in part, that ". . . [AWWA] hereby revokes and re-

Obviously, after this resolution, AWWA could not approve the grounding provisions of the 1935 National Electric Code. After considerable discussion, however, AWWA agreed to withdraw its opposition to the pro-

posed code provided that the whole question of grounding were referred to a committee formed of representatives from national organizations for detailed, impartial, and scientific study.

Research Committee

In the spring of 1936, AWWA and the Edison Electric Institute sponsored the organization of the American Research Committee on Grounding, comprising representatives of eighteen organizations from the fields of manufacturing, engineering, standards, inspection, contracting, and utilities. This committee was asked to determine if the grounding of electric circuits on water pipe created any adverse effects on the pipe or the water in pipe.

The report [8] of this committee corrected several false impressions regarding current flow in water pipe grounds. It had been thought that no current flowed over the customer's ground wire during normal operating conditions. When only one customer is served from a transformer, this is true, but when two or more customers are supplied from the same transformer, and a continuous metallic water pipe system connects these customers, it was shown that there is always some current flow (Fig. 2). The actual amount of current varies with the electrical load and with the relative resistance of the current paths.

Under abnormal conditions, such as previously described, large momentary currents will flow in the grounding conductors before primary fuses or overload devices can operate to isolate the hazardous condition. This is the protective action originally sanctioned by AWWA.

In its interim report,[8] submitted in January 1944, the committee summarized its findings as follows:

1. Grounding of electric power and lighting circuits is necessary for the safety of the customers and their property.

2. In general, grounding to metallic water pipes provides the highest degree of safety . . . because the resistance to ground of such pipes is generally lower than any other grounded metal body present . . .

3. The water piping system is of necessity in parallel with the grounded conductor of the electric distribution system . . .

4. In many cases the removal of alternating current from water service pipes or mains is difficult to accomplish.

5. No conclusive evidence has been found to date that alternating current of the magnitude measured by the committee has any appreciable detrimental effect on the pipes or on the water in the pipes.

6. If the recognized practice of grounding is not followed, there may be a hazard due to electric shock, ignition of gas, and sparking. If the grounding connection is not made on the street side of the water meter, there should be a bonding jumper around the meter to insure continuity of the grounding circuit when the meter is disconnected.

7. In about 10 per cent of the cases, the grounding installations were found to be defective.

1944 Policy Statement

Coincident with the publication of this report in April 1944, AWWA issued a statement of policy entitled "Grounding of Electric Circuits on Water Pipes."[9] This statement read, in part, as follows:

1. This Association will cooperate in all practices which lead to greater safety for the public. It will continue to consider all proposed measures, which are called safety measures, to see: (1) whether such measures have the importance attributed to them by their proponents; (2) whether the proposed practices are effective; and (3) whether the

practices are being proposed on the grounds of economy rather than fundamental merit.

2. This Association notes . . . that the grounding of electric services upon water pipes is understood to be desirable in the interest of safety of the users of electric current. It observes that water departments and companies do not install such connections; derive no benefit from them; may be damaged by them; and tolerate them only because of their reputed importance in providing electric service safely . . .

3. It maintains its general objections to the systematic interchange of stray electric current from electrical distribution systems to water pipes, and its unqualified opposition to the use of the water pipe system or its connections as an essential or integral current-carrying part of any electrical distribution. It is . . . not objecting to the current interchanges which occur during . . . brief and infrequent intervals when ground connections are fulfilling their specific protective purposes.

4. . . . the water works industry has not assumed, and does not now assume, any responsibility in the matter [of grounding], except it be in the protection of the structures which it maintains in order to serve its customers.

5. Water purveyors assume no direct or indirect responsibility or obligation in connection with the installation of water pipe ground connections, or for the maintenance of the integrity or continuity of any grounding attachment or connection made to a water pipe system.

6. Water purveyors reserve the right to use nonmetallic piping or pipe-jointing materials for mains, for service piping, or for house piping without *primary* regard to the effect that this may have on electrical grounding problems.

This statement has never been amended or rescinded.

Subsequent reviews,[10, 11] made in 1945 and 1951, have reaffirmed AWWA's position, and have further pointed out "that the water works industry views with suspicion the continued effort to write into the Code practices and policies which appropriate nonelectrical structures for electrical purposes without the knowledge and consent of the owners and users of such structures." [11]

Actions in California

Because of the population explosion in California and the correspondingly rapid growth in water suppliers, the California Section AWWA saw the need for standardized water service rules. No formal work was done, however, until 1949, when a special committee was appointed to prepare uniform water service regulations to be used as a pattern by all California water utilities. The committee report, titled "Tentative Regulations Governing Water Service," [12] was adopted by the California Section on Oct. 27, 1950, and published in the JOURNAL in April 1951.

With regard to grounding, the regulations state:

All individuals or business organizations are forbidden to attach any groundwire or wires to any plumbing which is or may be connected to a service connection or main belonging to the utility; the utility will hold the customer liable for any damage to its property occasioned by such groundwire attachments.

This statement, with minor changes in wording, had been in the service rules of many water utilities for some time, and has now been added to the regulations of many more. Unfortunately, it does not appear to have been actively enforced. Instead it seems to have been regarded as a "save-harmless" or "limitation-of-

liability" clause for the water system operator.

Following the publication of the standard rules, the grounding controversy again subsided, but new materials and techniques in the water supply field and more rigid electrical inspections resulted in renewed interest.

In 1957, the California Section AWWA formed a task group within its committee on pipeline electrolysis to resurvey the electrical grounding problem from both a technical and a legal standpoint. The first progress report of this group, issued in October 1959 (unpublished), reaffirmed the water industry's position that water utilities should not be required to provide the grounding devices for all other utilities or commercial enterprises.

The task group also stated that it had made contact with the attorneys for several water utilities in various parts of the United States and that the consensus was:

> 1. In the installation of a new service, the water utility generally could not be held legally responsible for providing a ground for other utilities. The owner of the property, however, should be notified when plastic tubing, insulated couplings, or asbestos-cement pipe is used by the water utility, and that these do not provide adequate ground.
>
> 2. In the event that a service is changed in an old installation and plastic tubing is installed, or insulated couplings are installed at the meter, the water utility would be liable for any possible damage unless the electric utility, the department of building inspection, and the owner of the property were notified that other means of grounding should be provided. This liability is based on the fact that unless adequate notification were given, only the water utility would have knowledge of the change in system.

Following receipt of this report, the East Bay Municipal Utility District, in the interest of public safety, issued a formal notice on Jan. 13, 1960, to all governmental bodies and building inspection departments in its service area which emphasized that "the use of water piping systems as grounding electrodes can be dangerous," recommended the use of other means of grounding, and quoted its regulation, which warns, "the district is not responsible for providing an electrical ground through water service equipment."

Simultaneously, the San Francisco water department, by means of new rules and regulations governing water service to customers, included the following prohibition:

> No one may attach any ground wire or wires to any plumbing which is or may be connected to any service pipe or main belonging to the department unless such plumbing is adequately connected to an effective driven ground installation on the premises.

For 40 years AWWA has consistently taken the position that it is in the business of supplying water, not electrical grounding facilities. The electric industry has just as consistently reiterated, through each succeeding issue of the National Electrical Code, that the safety ground for electric service shall be attached to the water piping. This stalemate probably would have continued indefinitely but for several occurrences in the last few years which have brought the issue into sharp focus.

Changes in Technology

Heavy requirements for metals by the national defense effort in World War II and in the Korean conflict

forced many water utilities to use substitute materials. Concrete or asbestos-cement pipe was installed in place of conventional cast-iron or steel mains. Several types of plastic piping were used in place of copper tubing or galvanized iron pipe for services.

At about the same time, plumbers, consulting engineers, and water utility operators became more aware of the high cost of corrosion, and began to use dielectric unions, insulating couplings and bushings, and insulating pipe joints, in an effort to stop electrolysis or galvanic action.

Then, after the Korean conflict, the cast-iron and steel pipe manufacturers found that in order to be competitive with concrete or asbestos-cement pipe on cost of installation, it was necessary to use rubber gasket joints in place of welding or packing.

Homeowners, faced with the problem of replacing corroded pipe between the water meter and the house piping, have turned to plastic tubing. They had already used this material in sprinkler systems, where it had proved to be economical, easy to install, and, best of all, did not need the services of a plumber, as no threading or soldering was required.

In hard-water areas, the demand for domestic water softeners was increased. Again, because of economy and simplicity of installation, many of these units were installed with plastic piping. Physically, most of them were placed between the water service pipe and the house piping, nullifying the electric grounding ability of the water supply system.

In 1959, the California legislature passed a bill to permit piping for gas and water service lines of asbestos-cement or approved plastic as well as steel, iron, lead, copper, and brass.

Action of Electrical Inspectors

In view of these new developments, the chairman of the northern California chapter of the International Association of Electrical Inspectors (IAEI), on Feb. 4, 1959, appointed a committee on grounding of services to investigate the problem of grounding in the absence of a continuous underground water piping system.

This committee submitted its first report in October 1959, and its final report and recommendation in June 1960. In essence, these reports stated that a continuous underground metallic water piping system is not presently available for electric grounding purposes, and that where it does appear to be available, it is likely to be disconnected.

The committee recommended that:

1. All ground connections to metallic underground water piping systems be supplemented by grounding electrodes
2. Where insulating fittings are used in water service piping, no bond be required, and the point of ground wire attachment be on the building side
3. Where the secondary system is grounded, the grounded conductors be run to each individual service.

The report and its recommendations were officially accepted by the northern California chapter of IAEI on Jul. 16, 1960. On Sep. 22, 1960, it was submitted to IAEI's Southwestern Section meeting. The delegates, representing the electrical inspectors in California, Arizona, Nevada, New Mexico and Hawaii, voted to accept the report and officially submit the recommendation to the National Electrical Code Committee.

Summary

The findings of the American Research Committee on Grounding,

IAEI's special committee on grounding, and the many other committees and individuals who have investigated the grounding problem all prove conclusively that the three original assumptions used as a basis for grounding electric equipment to water service piping are now largely false. Multiple electric services from one transformer *do* result in a continuous flow of alternating current on metallic water system piping; a metallic water service pipe does *not* indicate an electrically continuous, completely metallic water system; and the trend of water utilities to make repairs and replacements with nonmetallic materials probably *will* result in water systems that are useless for electric-grounding purposes.

The IAEI has taken a long step toward overcoming the grounding disagreement. To be sure that the National Electrical Code Committee understands that this is not a local or sectional problem, it is strongly recommended that AWWA support the IAEI action by supplying supplemental data emphasizing the extent of use of nonmetallic materials in water systems throughout the United States.

It appears that encouraging progress has been made. A changing technology, using new methods and materials for water supply systems, has done something that 40 years of AWWA policy could not do—it has taught the electric industry that, in supplying electric service to its customers, it should follow the lead of the gas and water utilities and supply an independent and complete service—including protective grounding facilities.

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Although the conclusions of this article are in basic disagreement with AWWA policy on grounding, it is presented here as a good statement of the electrical inspection authority's viewpoint on the matter.

Electric services are grounded for two basic reasons: (1) to protect persons and animals from the hazards of

electric shock and (2) to protect buildings and their contents from fire.[1]

The practice of grounding electric installations is well established and has been required by the National Electrical Code [2] for more than 40 years, but it is still controversial. Furthermore, there is a misunderstanding over what constitutes effective grounding.[3]

Function of Grounding

Grounding is accomplished on a 120/240-v distribution system by connecting a wire from the midpoint, or center tap, of the transformer's low-voltage winding to a copper-clad rod which is driven about 8 ft into the ground at the base of the utility pole. The purpose of grounding is to provide a path to the earth for any high voltages that may accidentally get on the low-voltage system. Accidental high voltages may be caused by an insulation failure in the transformer, by an automobile's hitting a utility pole, or by anything that makes the high-voltage conductors contact the low-voltage lines. As the high-voltage circuit is also grounded, high-voltage current flowing to the ground rod causes the high-voltage overcurrent device to open the circuit. When such a fault occurs, grounding prevents the voltage on the customer's premises from exceeding safe limits.

Another wire is connected at the midpoint of the low-voltage winding of the transformer. This wire, together with the other two wires from the low-voltage winding, is taken to the customer's service. The center wire is called the neutral wire. It is grounded at the transformer end by being connected to the same terminal as the transformer ground wire. It is also grounded at its other end by being connected to the customer's water service.

In the event of a mishap with the neutral wire, grounding provides a separate return path (through the earth) from the customer's ground to the center tap on the transformer. Even with a poor or open connection on the neutral wire, the overload devices (fuses or circuit breakers) on the customer's premises will be tripped by an overload or fault if the resistance of the ground return path is low enough. For the purposes of this paper, an adequate ground is one with 5 ohms or less resistance to the ground.

Advisability of Grounding

Some people argue that grounding a customer's wiring system increases the possibility of a person's receiving the full line voltage of 120 v if he contacts one live wire and is standing on the ground, or is in contact with a grounded surface. If the neutral were not grounded, these people point out, then someone in contact with both the ground and a live wire would receive only a slight shock if any shock at all.

The alternative to a grounded neutral wire would be an insulated system with no conductors grounded. This type of system is practically impossible to maintain without accidental grounds. If an accidental ground occurs on one live conductor—and the possibility of this is great—then someone in contact with a ground and the other live conductor could receive a voltage of 240 v on the conventional 120–240-v system.

The grounded system is safer because one wire is always grounded. If current on either of the other two wires should run to ground, the overload device on that wire will open the circuit. In such an event, it is easy to

determine which of the two wires is grounded because it is always identified by a white or natural gray conductor. With an ungrounded system, one of the three wires could be grounded without anyone's knowledge and set up conditions for a shock or fire.

In regard to fire protection, grounding improves the probability that the overload devices will function quickly. Thus the wires or conduit probably will not overheat and start a fire. Ungrounded systems that are accidentally grounded, or have poor ground resistance (10–15 ohms), do not allow enough current flow to trip the overload devices. For example, a 10-ohm accidental ground would allow no more than 12 amp to flow. The usual branch circuit overload device is set to trip at 15 amp. Therefore, the 12 amp would flow through the high-resistance contact point indefinitely and heat up the metal surfaces to a temperature that would readily ignite wood and other combustibles.

Code Requirements

The National Electrical Code requires that a-c systems be grounded if they can be, so that the maximum voltage to ground does not exceed 150 v. All distribution systems operating at voltages of 120–240 v and 120–208 v, and many at 240 v and higher, are grounded. This means that the electric services are grounded in all dwellings, most commercial buildings, and many industrial installations. The code further requires that this ground be an underground water pipe system if such a system is available.[2]

The code requires that there be no objectionable passage of current over the grounding conductors. It does not prohibit temporary currents which flow due to fault conditions while the grounding conductors are performing their intended functions.

In addition to the ground at the service, the code requires that the transformer be grounded to its own grounding electrode. With several customers on a single transformer, some utilities use the grounding at the customers' service instead of grounding at their own transformer. This provides a more satisfactory and reliable ground from the electric utility's point of view, but it may be part of the cause of electric currents on water pipe. Further study should be made on the problem before any definite conclusions are acceptable.

AWWA Policy

Following controversies on the grounding of electric circuits on water systems, AWWA stated in the April 1944 JOURNAL[4]:

> This Association will cooperate in all practices which lead to greater safety for the public. It will continue to consider all proposed measures, which are called safety measures, to see (1) whether such measures have the importance attributed to them by their proponents; (2) whether the proposed practices are effective; and (3) whether the practices are being proposed upon grounds of economy rather than fundamental merit. . . .
>
> It maintains its general objections to the systematic interchange of stray electric current from electrical distribution systems to water pipes, and its unqualified opposition to the use of the water pipe system or its connections as an essential or integral current-carrying part of any electrical distribution system. It is, however, not objecting to the current interchanges which occur during comparatively brief and infrequent intervals when ground connections are fulfilling their specific protective purposes.

This statement of policy appears consistent with the intended purpose of water pipe grounding that was set forth in the National Electrical Code. There is nothing in this policy that prohibits grounding an electric service to water pipe systems if the connection is made for safety purposes. AWWA is opposed to the use of such a connection when its primary purpose is to provide a return path to the electric utility's transformer during normal operation.

The "Interim Report of the American Research Committee on Grounding,"[5] presented in January 1944, clearly established that some water pipe used for grounding has current flowing over it much of the time, though no abnormal electric conditions appear to exist. The Department of Building and Safety of Los Angeles recently verified this condition. Currents of several amperes were found on some water pipe grounds.

It is clear that there are currents on some water pipe due to grounding, and that cooperative action should be taken by the electric utilities, the water utilities, and the inspection agencies to reduce these currents whenever possible.

Value of Pipe Grounding

The National Electrical Code requires that the water system always be used as the grounding electrode when it is available because it usually provides the lowest impedance to ground and, therefore, provides the best protective ground. The value of a water system as a ground is well expressed in the paper "Electrical Grounds on Water Pipes," by H. S. Warren[6]:

> The reason why a continuous metallic public supply water piping system makes the best ground is not because such pipes have water in them but is due to the fact that such a piping system has by far the largest contact surface with the conducting material of the earth. In fact, where such a piping system exists, it is the earth, electrically speaking, for all practical purposes. The hazard to be protected against arises from the fact that voltages may accidentally be set up between different metallic objects in the house and that persons may be subjected to these voltages. Water pipes appear at numerous points through the house and are interconnected or in contact with steam pipes, gas pipes, etc., so that they offer numerous chances for people to get in contact with them. If some other grounding electrode were employed instead of the water pipes, the voltages between electric wiring, apparatus, etc., and this extensive system of pipes might be much larger and, hence, the hazard much greater. The very presence of these piping systems in a house increases the importance of using them as grounding electrodes.

Electric appliances with water connections—garbage disposers, dishwashing machines, and timeclock-controlled regeneration-type water softeners—greatly increase the possibility of the water system's becoming energized due to an insulation failure.

Insulated Fittings

A serious threat to the electrical continuity of the water pipe is the use of an insulated fitting, or dielectric coupling. The purpose of the insulated fitting is to reduce galvanic corrosion. For galvanic corrosion to occur, two dissimilar metals must be connected in the presence of an electrolyte. Salt water and acid solutions are excellent electrolytes. Ordinary potable water is a weak electrolyte. The weaker the electrolyte is, the less the galvanic action. In fresh water galvanic corrosion is not common.

Often any form of corrosion not clearly understood is wrongly attributed to electrolysis, electrolytic action, or galvanic action.

Normally, plumbers are worried about galvanic corrosion when they connect the iron mains to a building with copper pipe. To limit galvanic corrosion, the plumbers frequently place an insulated fitting, or dielectric coupling, at this connection. In order to protect the occupants of a building against the hazards of electric shock, Los Angeles insists that the electrician install a copper strap, or bonding jumper, around all dielectric couplings in order to maintain electrical continuity. Thus the bonding jumper defeats the purpose of the insulated fittings. Yet Los Angeles has not received any complaints that could be positively attributed to galvanic corrosion.

A more practical method of solving the problem is to place a 6-in. iron nipple between the main and the copper pipe in the house. If galvanic corrosion does occur, it will be in this 6-in. nipple. This "suicide nipple" is expendable, can be readily replaced if necessary, and will assure the continuity of the electrical ground. Experience to date would indicate that there will be few instances of serious corrosion at this connection.

Undue emphasis is placed, apparently, upon galvanic corrosion in pipe inside buildings. Furthermore, many of the dielectric couplings that have been used in Los Angeles are of questionable value, because if galvanic corrosion did exist, it is doubtful that they would protect the piping system.

Nonconductors

The resistance of a pipe system to ground varies inversely as the area of metal in contact with the earth. The use of asbestos-cement water mains will obviously reduce this area and, therefore, increase the resistance to ground.

The Los Angeles Building and Safety Department conducted tests on the electric service grounds on several residences and found that the resistance of those pipe systems with asbestos-cement mains was higher than that of systems with cast-iron mains, but was still within a safe range and was materially lower than could have been obtained with any other type of grounding electrode available. This may be because water meters in Los Angeles are usually at the curb line and, therefore, the contact area of the metal pipe between the house and the meter keeps down the resistance to ground.

Ground resistances on ten representative electrical services in residences, some with cast-iron mains and some with asbestos-cement mains, varied from a high of 2.7 ohms to a low of 0.4 ohm. The median value was 1.1 ohms. These resistances are satisfactory for protection purposes. Therefore, it is concluded that although asbestos-cement mains do increase the resistance to ground, a dangerous condition is not created if the connection from the house to the curb meter is metallic pipe or if there is other underground metal pipe on the premises.

The use of plastic pipe between the corporation cock and the meter will also increase the resistance of the water pipe system. If the meter is located at the curb line, the effect does not appear to be any more serious than that of the asbestos-cement street main.

The Los Angeles Electrical Code [7] does not require that the grounding conductors be connected on the street

side of the water meter. In Los Angeles, where the water meter is at the curb line, a connection with the street side of the meter would require a long grounding conduit and conductor. Experience has indicated that this practice is not warranted in Los Angeles.

Gas System Ground

The National Electrical Code permits the use of a gas pipe system for grounding if the water system is not available. ASA Z21.30, "Installation of Gas Appliances and Gas Piping,"[8] requires that gas pipe within a building be electrically continuous and bonded to any grounding electrode recognized by the National Electrical Code.

This standard further prescribes, in part, that underground gas service pipe not be used as a grounding electrode unless it is an electrically continuous, uncoated metallic pipe and its use is acceptable to the gas supplier and the inspection authority.

In the Los Angeles area, the gas companies use wrapped or coated pipe on house services, so the gas system does not provide enough metallic contact with the earth to be used as a ground. In an American Gas Association survey of 23 gas companies throughout the United States, it was reported that many of them used insulators in the gas service or at the gas meter.[9] These insulators would eliminate the use of underground gas pipe as a ground.

Gas pipe within the building, however, is invariably connected to the electric system when metallic wiring enclosures are used, and it is indirectly connected to the electric system in nonmetallic wiring systems through the water pipe. This interconnection is usually at the water heater, but may also occur at the forced-air furnace or at built-in, electrically controlled, gas ovens or range tops.

Tests made by the Los Angeles Building and Safety Department indicated that the resistance between the gas and water pipe systems in dwellings varied between 0.01 ohm and 0.12 ohm. This indicates that, although no attempt was made to connect these systems, they were electrically tied together.

Drain Pipe Ground

The drain system in a house consists of the main drain of 3-in. or 4-in. cast iron, and galvanized- or cast-iron pipe varying in size from 1 to 2 in. It also includes vent pipes for individual plumbing fixtures, as well as the stack vent for the entire system. The Uniform Plumbing Code[10] requires that the main drain terminate not less than 2 ft from the outside wall of the building. At its terminus it is usually connected with clay pipe that leads to the sewer or septic tank. Because the cast-iron soil pipe is buried only 5–12 ft, and because it is coated with tar, it is usually not as effective a ground as a water service system.

According to tests made by the Los Angeles Building and Safety Department, resistance between the water service and the drain system is even lower than between the water and gas systems. In these tests, the lowest resistance measured was theoretically zero and the highest was 0.2 ohm. This is a further indication of the electrical continuity between the various pipe systems within a building.

Driven Ground Rods

Most electrical codes do not allow the use of made or driven ground rods

unless other underground metallic surfaces, such as the water service, gas service, or the metal frame of the building, are not available. In Los Angeles, driven rods have not proved satisfactory as grounds. The minimum resistance measured on representative driven ground rods, which had been in the ground several months to allow compaction of the earth, was 10 ohms. Most of the driven ground rods tested offered several times as much resistance. Some driven rods with a resistance of several hundred ohms have been known. These resistance values are far too high to afford protection from a shock or fire hazard.

Bonding of Pipe Systems

Evidently it is usual for the interior pipe systems in residences to be interconnected. The resistance between these various piping systems and ground varies, however, so that it is possible to receive a shock between the water pipe and the drainage pipe or the gas system.

The Los Angeles Building and Safety Department has records of persons' having received shocks between the kitchen sink and the kitchen sink faucets. Usually the cause has been traced to defective insulation on a garbage disposer that was connected to the drain pipe. In these instances it is doubtful that the water pipe and the drain pipe were electrically connected.

This type of shock hazard could be eliminated by bonding together all pipe systems in a building with a copper conductor. The bond should be made in a location that would be accessible for inspection. If this were done, as many electrical inspection authorities have advocated,[11] shock hazards in homes would be reduced considerably. It is impossible to receive a shock between the various pipe systems if all metallic pipe is at the same relative electrical potential. If an insulation failure occurred on a metallic wiring system, the circuit breaker or fuse would clear the circuit.

Stray Currents on Water Pipe

The subject of stray currents on water pipe has been discussed by several investigators.

One of the oldest reports is the paper entitled "Promiscuous Electric Grounding on Water Service Pipes and Mains," which appeared in the October 1933 JOURNAL.[12] The authors were concerned about the electrolytic action due to grounding electrical services on water pipe. They concluded that alternating current produced about 1–2 per cent of the corrosion caused by an equivalent direct current. After making their investigation, it was their opinion that more study should be made on the subject of the effect of grounding a-c systems to water pipe.

Under the auspices of AWWA, a fact-finding report, entitled "Report of a Research Project on the Effects of Electric Grounding on Water Pipes," was prepared.[13] This report described an investigation comparing pipes of four materials—red brass, copper, galvanized iron, and lead—and the effects of stray current flowing through the pipe when it was also carrying potable water. This investigation concluded that electric grounding with alternating or direct current of 1.25 amp in $\frac{3}{4}$-in. red-brass, copper, galvanized-iron, or lead pipe had no appreciable effect on the quality of the water passing through the pipe.

The most recent report was the "Interim Report of the American Research Committee on Grounding," issued in 1944.[5] The committee did a very

thorough job of investigating 87 instances of alleged corrosion because of grounding. Not a single one was authenticated as corrosion due to grounding. The committee report states: "No conclusive evidence has been found to date that alternating current of the magnitude measured by the committee has any appreciable detrimental effect on the pipes or on the water in the pipes."

The committee did discover, however, that there were stray alternating currents flowing on water pipe even when the electrical circuit was in normal operation. This was a new observation that had not received serious consideration in previous studies. In order to insure more effective and permanent ground connections to water pipe, the committee recommended that methods and devices more satisfactory than those now available should be developed.

The Los Angeles Building and Safety Department recently spot-checked 49 water pipe grounds and found current on eight of the pipes. In addition to these eight installations, fourteen more had current on the electric ground, but owing to the large size of the water pipe it was not possible, with the equipment available, to determine if the current was also on the water pipe. In most pipe, the amount of current was negligible. There were, however, several in which currents were found. They varied from 0.5 amp to 8 amp. Several of these installations have been corrected by tightening the neutral connections. The rest are being surveyed for remedial action.

Conclusions

1. The water system is the best grounding means available today, even with asbestos-cement mains and plastic street connections, provided that there is more than 10 ft of buried metallic water pipe on the premises.

2. Insulated fittings or dielectric couplings are of questionable value in preventing galvanic corrosion and greatly increase the hazards of shock and fire. They should not be installed in water services.

3. All pipe systems within a building should be electrically bonded together to reduce the fire and shock hazard. All isolated pipe systems should be bonded to grounded pipe.

4. There is no conclusive evidence that stray alternating currents from grounding on water systems materially influence electrolysis, electrolytic corrosion, or galvanic corrosion.

5. Electric utilities, water utilities, and inspection authorities should cooperate in preventing unnecessary currents on water systems.

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Monthly Water Bond Interest Costs and Sales

A report of the Chief, Basic Data Branch, Div. of Water Supply & Pollution Control, US Public Health Service, Washington, D.C.

Month	1960–61 Net Interest Cost—*per cent*		Total Bond Sales—*$1,000,000*		
	General Obligation Bonds	Revenue Bonds	1960–61	1959–60	1958–59
Feb.	3.99	4.26	41.7	62.1	56.7
Mar.	4.12	[illegible]	19.5	57.0	24.8
Apr.	3.95	4.49	38.2	44.4	40.0
May	3.79	4.29	49.9	105.5	22.7
Jun.	3.77	3.77	111.4	50.3	20.1
Jul.	3.99	3.93	33.1	17.3	39.0
Aug.	3.34	4.02	48.4	25.5	37.7
Sep.	3.82	3.75	18.8	16.6	14.3
Oct.	3.64	3.85	21.0	68.4	60.8
Nov.	3.36	3.86	18.4	36.3	42.5
Dec.	3.55	4.20	77.3	18.4	11.5
Jan.	3.88	3.70	37.8	21.2	28.3
Total			515.6	523.0	398.4

Gathering and Use of Water Quality Data

A Symposium

A series of papers presented on Aug. 29, 1960, at the Symposium on Water Quality Measurement and Instrumentation, Cincinnati, Ohio. The symposium was sponsored by the Robert A. Taft San. Eng. Center and the Div. of Water Supply & Pollution Control, USPHS.

Utility Needs—*Samuel S. Baxter*

WATER utilities cannot produce high-quality water without adequate data on fluctuations in raw supply, functioning of treatment and distribution equipment, and finished product quality.

High quality is taken to mean both the absence of pathogenic organisms and considerations of taste, odor, color, hardness, and similar characteristics. To utilities that must use water sources from surface streams, particularly those streams used for disposal of sewage and industrial wastes, both treated and untreated, the subject of water quality is of special interest.

Treatment Progress

The problem of water quality is changeable. In communities that originally used wells, pollution reaching the wells often caused the community to go to a surface stream. In Philadelphia this happened as far back as 1799. From the standpoint of sanitary quality, taste, and odor, the resultant product was far inferior to that turned out today, even if the streams were not badly polluted then.

Succeeding generations demanded water of a higher quality, especially where public health and water officials showed that disease organisms existed in water, and that these organisms could be removed. The same thing applied to taste and odor. As a result, from time to time new procedures were installed, beginning with simple sedimentation. Philadelphia has now reached the stage where it is completing the second set of filter plants.

It would be irresponsible to assume that scientists and engineers have discovered, in water, all the pathogenic organisms or substances that will ever be isolated. Because there has been an increasing demand for better quality in practically everything citizens use, they will demand better tasting water, or at least water from which objectionable tastes and odors have been entirely removed.

Modern water treatment plants can provide facilities for the production of water that is free from disease—at least as it is known today—and is readily acceptable from the standpoint of taste and odor. These treatment facilities include all the well known mechanical processes of sedimentation, mixing, and filtration, and the addition of many chemicals for disinfection, fluoridation, corrosion inhibition, and treatment process assistance. It can

be truly said that water of this type is a manufactured product.

Quality Control

Quality control is certainly not a new subject, nor is it the concern of water utilities alone. It has always been the concern of everybody from the chef in the kitchen tasting the soup to the engineers in chemical and metal industries running their complex tests. In most manufacturing processes, the emphasis is on continuous high quality. One bad kettle of soup may permanently drive customers away from a restaurant, and one bad batch of steel may cause a failure in the member of which it becomes a part.

The water industry has been somewhat alert in recent years to the importance of water in health. Chlorination destroys pathogenic organisms, or at least it destroys those known.

In many instances, however, the industry has not been equally alert on the matter of taste and odor quality. Usually, raw-water samples are taken every 3 or 6 hr, and perhaps less frequently during the night. If between tests some slug of chemical waste reaches the intake, or the washdown from some decaying vegetation reaches the plant, water from this source may go through the treatment processes getting the same treatment that raw water of a different quality receives. It is even possible that poisonous substances might enter the plant without the immediate knowledge of the operator.

The procedures at modern filter plants are exemplified by the testing work at the new Philadelphia Torresdale plant on the Delaware River. Tests for turbidity, alkalinity, and pH are made every 3 hr. Most of these tests are either automatic or can be accomplished in less than 10 min. Taste and odor tests are run three times in 24 hr, with these tests taking perhaps 10 or 15 min to accomplish. Other tests, such as hardness, chlorides, nitrates, phosphates, manganese, and iron, are run only once a week. Several of these tests take more than an hour to perform.

In addition to the normal tests that are required to produce high-quality water, many water plants in industrial areas are faced with the problem of accidental spills of dangerous and poisonous chemicals. Within the last 10 years, the Philadelphia Torresdale plant has dealt with two such spills involving a cyanide compound. In one of these instances, more than 2,200 lb of acetone cyanhydrin was spilled into the river about 5 mi upstream from the water plant intake. In recent months, an accidental discharge of endrin, an insecticide, caused serious trouble and concern. Where such upstream hazards are known to exist, automatic information on spills would be valuable to the water plant operator.

Modern plants like Torresdale, which was placed in operation late in 1959, have complete automatic facilities for chemical application and other operations, including filter washing. When the chemist sets the ratio of chemical application, the chemicals are fed in the proper amount with automatic adjustments for flow variations. With this type of equipment, the water is receiving the treatment that the chemist decides upon.

But once the ratio of application is set, it is not changed until samples of raw water and samples from water throughout the plant are tested. During these intervals, the quality of final water can vary.

Control Improvements

If data on the quality of water were available immediately and continuously, the plant chemist could make the necessary adjustments as the quality of the raw and finished water changed. With automatic feed of chemicals, his decisions could be transmitted immediately to the various points of application and treatment. Such an operation would require instruments that report immediately on crucial water characteristics.

Some of these instruments might have to be remote from the plant, especially those that sample such raw water conditions as dissolved oxygen, BOD, and evidence of phenol pollution—the bane of most water plant operators in industrial areas.

The second step in automation would be to transmit information to the laboratory for the immediate knowledge of the chemist. For readings within the plant area, ordinary telephone lines would be sufficient. For much longer distances on the river, the same type of telephone wires or a microwave system could be used.

With all the information in front of him, the plant chemist should be able to adjust his treatment procedures minute by minute if necessary, and to change the proportion of chemical feed automatically as he makes his decisions. Because many of the combinations would be routine, a high-salaried chemist would not be required to make most of the decisions. One trained to observe the proper readings and to do the prescribed things could handle most of the job.

The last step would be to use a digital computer in whose memory all possible combinations of raw-water data were stored with the corresponding treatment required. The computer could automatically send to the chemical plant, without the intervention of a chemist, orders for chemical dosage and other treatment procedure. Once in a while, perhaps, a combination not stored in the computer's memory would occur. This would ring a bell, light a light, and wake up the shift chemist on duty, who would either make a decision himself or call for help.

Current Status

All this may sound fantastic, but it should not be so to anyone who has observed what is being done in instrumentation and automation. A short review of what has been done in Philadelphia along the Delaware River may point out how far one utility has advanced to this type of operation.

Along the upper Delaware, the Lehigh Water Resources Research Council is developing and installing automatic machines for monitoring water quality. At the present time, a station on the bridge at Riegelsville is taking automatic samples that record temperature, pH, conductivity, sunlight intensity, turbidity, and dissolved oxygen.[1]

The Philadelphia water department has been interested enough in automatic instruments for quality measurements to install several such instruments on the Delaware River. The department plans to install others on the Delaware and Schuylkill rivers. Most of this work has been done jointly with the US Geological Survey. In the summer of 1960, instrumentation to measure continuously dissolved oxygen, temperature, and specific conductance was installed on the Delaware a few miles below the Torresdale water plant, a point which is within the tidal

influence at the plant. In October 1960, instruments that measure pH, specific conductance, temperature, turbidity, and dissolved oxygen were ordered for installation at Trenton, upstream from the Torresdale plant.

Similar installations covering one or more of these parameters are scheduled for the next 12 months at various points on the two rivers that furnish water supply for Philadelphia. All of these continuously record data on charts which have to be picked up from time to time.

Automatic monitoring equipment to measure radioactivity has been purchased and is now undergoing tests. This equipment will record radioactivity on the Delaware and Schuylkill rivers. The Philadelphia water department is helping to test and operate experimental equipment for the continuous measurement of phenols.

Development of Instruments

Instrument makers are becoming aware of the need for automatic testing instruments in the water industry and related industries. One manufacturer has a list of instruments that will provide for continuous measurement of 50 water quality factors and related variables. Most of these instruments are in various stages of development, and some have already been completed. Instruments to measure at least fourteen other variables are under discussion and review. These variables are some of the really difficult ones to measure, such as ammonia nitrogen, chlorine demand, coliform organisms, and BOD.

In regard to transmitting the data from the instrument to a central point, so much has been accomplished that this phase should produce only minor problems. Using Philadelphia as an example again, a load control center that handles quantity, pressure, height, and other hydraulic elements of water supply has been placed in operation. Information from the various gages and instruments scattered throughout the city is transmitted through a system of land wires and microwave stations to a central point. At this point the information is decoded and typewritten. Transmission and typing of this information are done at the rate of one station per second, and four stations per second are scanned for faults. There should be little trouble in transmitting quality information to and from a central point if we can get the instruments and measuring devices to measure automatically the desired parameters.

Present Obstacles

Two obstacles prevent more rapid adoption of automatic instrumentation. First, those in the water industry must be willing to decide that this type of automatic operation is necessary, and to take the steps required to put it into effect. Secondly, economic justification for the necessary expenditures must be provided.

The water quality data symposium at Cincinnati will help encourage serious thought on the need for the various instruments and equipment. A substantial number of water works people will have to show interest to induce laboratories, universities, research centers, and manufacturers to spend time and money developing this equipment.

Economic justification is a somewhat different problem. With the Philadelphia utility, it was not too difficult to justify buying a new pump if it could be shown that the power savings were more than the carrying charges on the cost of the new pump.

Justifying quality in dollars and cents is another thing. If people are receiving poor water, they might be willing to pay more to get better water, although the measurement of such benefit is almost impossible. The problem becomes more difficult with a system that already produces good water but wants to turn out excellent water by using the equipment mentioned in this paper.

Philadelphia faced this problem with its load control center. It was certainly a great improvement to get practically instantaneous information on all phases of the system, compared with the old method of a few telemeter gages and telephone reports. The department was asked, however, why it couldn't get along with the same equipment in the future, if it got along without the new gadget in the past. The department answered that by installing a supervisory control system with the load control center, operators could be removed from remote pumping stations. This alone saves far more than the carrying charges on the new equipment, and the department has better information available and available at once.

This might be the best economic approach to automatic quality control. It would seem that such instrumentation could be better justified in a large water works system, and one that has difficult and changing characteristics in raw water. The real savings, however, are made by reducing laboratory, field, and operating personnel.

If operators are willing to point out the requirements and the benefits, they will find men in the instrument field to develop the needed equipment, and will be able to justify the necessary costs.

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Consulting Engineer Needs—*Paul D. Haney*

A paper presented by Paul D. Haney, Black & Veatch, Consulting Engineers, Kansas City, Mo.

All aspects of water quality are of interest to the consulting engineer. In addition to obtaining information, he should encourage the interpretation and publication of data, as collecting data that are promptly filed and forgotten, or are improperly reported, is wasted effort.

A consulting engineer working on water supply and waste water disposal encounters a variety of problems involving everything from soil mechanics and structures to chemistry and biology. Generally, the engineer has only a limited time to solve the problems associated with a particular project. Often the problem is a critical or controversial one. If it were not, the engineer probably would not have the job. In many instances the consultant has to dig out and work with the data available. He usually has to gather his own water quality data. Often he cannot find the information he needs—particularly where ground water is involved. Then the information he does find may not be as useful as he hoped it would be. Finally, the engineer must distinguish the relevant data from the incidental.

Although collecting and tabulating data are important, data alone will not solve problems. Interpreting data is the next step. This requires a knowledge of what is important to the specific situation and what is not.

Essentially, the consulting engineer's needs for water quality data do not differ from those of any other investigator concerned with the use of water resources. Physical, chemical, and biologic data are all of interest to him. Depending on the engineer's particular problem, certain aspects of water quality may be much more important than others. For example, in judging the suitability of a proposed well for a city, the engineer would be much more concerned about data showing a trend toward increased saltiness than about a similar trend toward higher hardness or iron content. The latter constituents can be reduced by treatment, whereas it is generally not feasible to install facilities for the removal of salt from a municipal water supply. Certainly the engineer would want to take a long, hard look at the alternatives before embarking on a saline-water conversion program for a city supply.

Sources of Data

Water quality data may be available from numerous sources. Some of the best sources are USPHS, USGS, state health departments, state and interstate water pollution control agencies, state geological surveys, universities, and drilling contractors. Water treatment plants and industries, notably power plants, are also excellent sources of data. The data published by the National Water Quality Network are worthy of special notice.[1]

Insufficient Data

The principal complaint about water quality data is that there is not enough of them. The problem, as usual, is money. Because much information about the collection and processing of data has been published, it would also be interesting to read a discussion on how to finance the collection and tabulation of data. Data are a matter of concern to everyone, yet relatively few are aware of their great importance. Somehow the story must be taken to the people who eventually pay the bill.

Notable data deficiencies are encountered particularly in the field of ground water resources. Most smaller cities in this country, many large ones, many industries, and thousands of farmers are dependent on ground water. Despite the obvious importance and value of our ground water resources, it is surprising how little we know about them. Probably some ground water resources are being overexploited, while others remain to be discovered, or their potential to be assessed. Subsurface pollution, an insidious destroyer of ground water resources, has not received enough attention.

If a consulting engineer is interested in data, he must be interested in accurate data. There is too much sloppy laboratory work done, and too many data are worse than useless because of gross inaccuracies. To compound the confusion, good data are sometimes improperly reported. Data are sometimes reported so vaguely that the users do not know what they are talking about. For example, chloride—a constituent of common salt—is universally present in natural waters. Sometimes it is reported as chloride

ion (Cl^-), and sometimes, unfortunately, as sodium chloride (NaCl). This is not a serious matter if the distinction between the two methods of reporting is made absolutely clear. Often it is not. A water that contains no more than 400 ppm of chloride expressed as NaCl is fairly satisfactory for municipal use, but one that contains 400 ppm of chloride expressed as Cl^- is unsatisfactory. It is easy to imagine the confusion that will arise if several laboratories reporting chloride results do not clearly indicate the terms in which the chloride data are reported. Other examples of confusion could be cited. Therefore, special advice to engineers and others who must interpret results of water analyses seems appropriate. The interpreter should read the fine print on the analysis report as he would the fine print in a contract. Sometimes he will be surprised at how the results are reported.

Correlative Data

Certain correlative data are important to the engineer studying a water quality problem. These correlations may include hydrologic and water use data, information on sources of pollution, and geologic information.

Of the hydrologic data available, probably the streamflow records that are collected, analyzed, and published by the USGS, in cooperation with state agencies, are the most useful. A recent USGS publication on flow-duration curves,[2] for instance, describes the preparation of a water quality frequency curve.

Chloride data for the Smoky Hill River at Enterprise, Kan., will illustrate the importance of streamflow data in connection with the interpretation of water quality information (Table 1).[3] On the basis of quality data alone it would be difficult to give an intelligent answer to the question: "What is the chloride concentration in the Smoky Hill River at Enterprise, Kan.?" Averaging the data would only be good for practice in arithmetic. To interpret these results correctly it is necessary to consider streamflow. During the sampling period, flows at the Enterprise gage ranged from about 50 cfs to more than 14,000 cfs. This variation in flow had a profound effect on water quality. The clear-cut reciprocal relationship between chloride concentration and flow is shown in Fig. 1. This is for illustrative purposes only. Not all available data were used and more refined plotting procedures are possible. No attempt was made to analyze statistically the relationship between flow and chloride concentration. It is virtually certain, however, that statistical analysis would show a high correlation coefficient, indicating a close reciprocal relationship between chloride concentration and streamflow. In the Kansas Board of Health water quality publication that supplied these data, flow data are tabulated along with quality data. This proce-

TABLE 1

Chloride Ion Concentration in Smoky Hill River at Enterprise, Kan.

Date of Sample	Cl^- *ppm*
Nov. 15, 1956	450
Dec. 17, 1956	925
Jan. 29, 1957	1195
Feb. 20, 1957	885
Mar. 27, 1957	670
Apr. 25, 1957	214
May 20, 1957	14
Jun. 26, 1957	18
Jul. 29, 1957	74
Aug. 26, 1957	113
Sep. 18, 1957	50
Oct. 31, 1957	117
Nov. 29, 1957	279

dure is a sound one; its widespread use is recommended.

Distribution System and Water Quality

The author's experiences as a state sanitary engineer and a consulting engineer have focused his attention on what he considers an inadequately explored factor in water quality. The problems of supply, treatment, and pollution control have been so numerous and pressing that, naturally, a great deal of study and research effort has been concentrated on them. The customers who pay the bill, however, judge their utility operators not by good intentions, but by final performance. The water consumer is equipped by nature with extremely sensitive testing apparatus. With his senses of taste, smell, and sight, the consumer routinely monitors the water supply. The sampling point is the water faucet in his home. Here, not at the water treatment plant, is where quality is judged. It matters little to the consumer that a quality product may be leaving the water treatment plant. It is what is delivered to him that counts, and there are many opportunities for water quality to deteriorate in that vast complex of tanks, buried valves, and pipes that make up the distribution system. Although a high proportion of the money invested in water systems is spent on distribution works, much remains to be learned about distribution systems, particularly about how systems and water quality affect each other. It is true that the water industry has learned much about quality problems in the distribution system. Between 1940 and 1955 the JOURNAL published several articles on quality maintenance in distribution systems. Dozens of others appeared on cross connections, pipeline growths, and corrosion. Nevertheless, utility managers, water supply engineers, chemists, and consulting engineers need to know more about the attenuated chemical and biologic reactions that most certainly occur in distribution systems.

It is not easy to visualize the difficulties that may be encountered in the distribution system. To establish a crude frame of reference for the problems, the following calculations are submitted. For a city with a population of 25,000 and an average water use of about 3 mgd, the estimated internal area of the water mains is 17 acres, or about 0.7 acre per 1,000 water users. Similar computations for a typical portion of the distribution system of a city having a population of 750,000 gave a value of 4.7 acres per square mile of urban area, corresponding, roughly, to 0.7 acre per 1,000 consumers. Calculations based on statistical data [4] suggest that a value in the neighborhood of 0.6–0.7 acre of pipe surface per 1,000 consumers

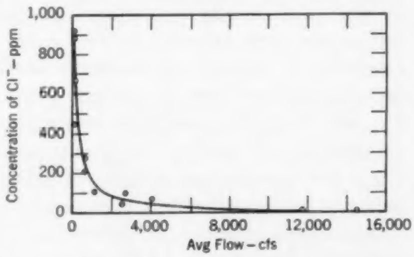

Fig. 1. Chloride Concentration and River Flow

Flow of the Smoky Hill River at Enterprise, Kan., was at indicated level when sample of indicated concentration was taken. The Kansas Board of Health supplied the chloride data; USGS supplied the flow data.

is reasonably representative. Whether the value is a half-acre or an acre is of no great significance. In either case, the area of pipe exposed to water is substantial, and there must be great opportunity for slow chemical or biochemical reactions to occur at the pipe-water interface. Many of these reactions may produce adverse effects on water quality. We have ample evidence that water quality is not, as a rule, improved during distribution. Furthermore, the area calculations are based on the assumption that the pipe is smooth. Corrosion of the interior of the pipe would probably increase the active area exposed to the water. Doubtlessly, many other interrelated factors, such as time of contact, velocity, and turbulence are also important.

Another calculation is of interest. First, the investigator assumes finished water is pumped through 1 mi of 12-in. transmission mains. A conservative hydraulic load for a 12-in. main is 1 mgd. The investigator assumes this main has been in service for 10 years, which is perhaps one-tenth, or less, of its life. The pipe, it is further assumed, continuously carries water at a rate of 1 mgd, and the water, through some chemical or biochemical reaction, deposits 0.1 ppm of material on the pipe surface. This might be organic "goo," iron oxide, or calcium carbonate. At the end of 10 years, if the deposited material all sticks, the pipe surface will be coated with about 1.5 tons of whatever was deposited. If the deposit were uniformly distributed over the interior of the mile of pipe, its thickness would be less than 0.1 in. and it might not have much effect on the hydraulic capacity of the pipe, but if, after this 10-year period, water treatment procedures were altered slightly, would the deposit stick or would it break loose and be discharged in small chunks at the end of the pipe? If the deposit were organic material and the chlorine residual at the water treatment plant changed from a mild (combined) residual to a "hot" (free) residual, would tastes and odors result from interaction of the organic matter and the hot residual? Finally, if any of these things happened, would the customers find them objectionable? These and many other questions can be answered only if more is known about the ways distribution systems and water affect each other.

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Industry Needs—*Milton F. Schaible*

A paper presented by Milton F. Schaible, Mgr., Technical Dept., Libbey-Owens-Ford Glass Co., Ottawa, Ill.

For United States industry, water has been a cheap service commodity, generally free for use with modest extraction cost. Except for certain arid districts, it has usually been abundant in supply and moderately satisfactory in quality.

Improvements in equipment, processes, and product development have prompted industries to seek more and

better water. Although the needed amounts of water are only occasionally hard to find, the quality of raw water has been deteriorating because of pollution. Fortunately, through the efforts of government, public-spirited citizens, and many organizations, pollution appears to be partially arrested. Nevertheless, it has increased the cost of water conditioning, necessitated changes in treatment standards, and added great volumes of water to that which must be treated.

While the water that industries use has become more polluted, all their other costs have risen, forcing them to produce more goods more efficiently. To a large extent, technologic developments have enabled industries to increase production and efficiency. These technologic developments, in turn, required closer tolerances in water quality.

This background explains the need of industry for sustained collection of basic water data.

Value of Data

Experts disagree on the economic importance of industrial water treatment. Some point out that the cost of water treatment does not represent a large proportion of production costs. Others note the cost of equipment failure, production loss, and other expensive malfunctions that would occur if water quality were not precisely controlled. The exact importance of water quality to many processes has never been adequately established. Closer tolerance, ease of manufacture, higher quality, and lower reject percentages may be gained through precise water quality control.

Reliable control depends on a well organized, sustained data program. Such a program must monitor the water both before and after conditioning.

In a single plant, many different processes require water of different quality tolerances. A treatment facility that once met the requirements of all the plant's processes may be inadequate for new processes. Thus the water services operator may have to adjust his conditioned water for specific applications. This is an unsatisfactory compromise. A sustained data program can, in addition to pointing out areas of inadequate control and fluctuations in raw water supply, also aid water service operators in obtaining suitable equipment or additional capacity.

Uses of Data

The uses of sustained water quality data in industry are many. As a process tool, water may be used to produce or transmit energy. It may segregate, dissolve, clean, cool, heat, transport, or disperse things. As a raw material, it may emerge as part of the product. It is also used for sanitation and fire protection. Which basic factors a data program will measure depends on the plant's particular uses of water. Industries cannot afford to measure irrelevant factors.

In general, water quality data serve the following purposes:

1. To help operate the plant's water treatment facility
2. To investigate the treatment problems and factory applications of water
3. To help substantiate appropriations for treatment facility improvements
4. To serve as a record on which to base future planning.

In operating water treatment facilities it is desirable to know the seasonal fluctuations of the water supply, the rapidity with which these fluctuations occur, and the range through which

they deviate. By recording the frequency of unseasonal deviations, unaccountable variations may be traced to their source. Water quality fluctuations may determine the current seasonal inventory of raw materials, the manpower schedule, the maintenance and overhaul program, and even the vacation schedule. With considerable experience under stable load conditions, it is not unusual to predict the operating conditions of the treatment plant by the area weather report. Because few industrial water conditioning facilities are more than adequate, any reasonable clue can usually help.

Much of the water that industries use is untreated and unconditioned. Sustained data concerning this water can be helpful in tracing plant process difficulties or in correlating water quality with product quality.

Different water qualities may be required in the same industry, and requirements within a factory change. At the same time, fluctuating corrosive characteristics, organic inhibitors, dissolved solids, alkalinity, pH, biologicals, colorants, temperature, and volume available—to mention just a few factors—could change production allocation or expansion planning. Data on each of these factors enables an industry to accommodate for their variations.

Few water service operators in industry could approach management with an unsubstantiated request for a capital expenditure. To substantiate their need for improved facilities, operators must have sustained water data shown in relation to plant production data.

In industry's plans for future growth, sustained water data are invaluable. Experts predict an increase of at least 100 per cent in the use of industrial water within the next 15 or 20 years. Will the water be available, and in usable quality, when it is needed? Only a basic data program can answer this question. Intelligent planning for expansion can be accomplished only by studying historical data.

Data Application

Safety plate glass manufacture is one industry for which water quality is an important factor. As much water is used to make a ton of glass as is used to make a ton of steel. Because the water quality requirements for glass are generally critical, much of the water is either conditioned or is under process control.

The author has dealt with water quality problems at the glass plant located a mile below Ottawa, Ill., where the Fox and Illinois rivers flow together. The Illinois River originates at the confluence of the Des Plaines and Kankakee rivers. At about the turn of the century, the city of Chicago constructed a sanitary drainage canal as the connecting link between the Chicago and Des Plaines rivers. This diverted sewer discharge away from Lake Michigan, the city's prime source of drinking water. As a result, the Illinois, a river formerly known as a fisherman's paradise, became virtually an open sewer. From the 1920's to the mid-1930's, not even vegetation would grow along its banks.

Steps were taken to alleviate this pollution, but the glass plant was affected. Besides the sewage from Chicago and the junction of the Fox River just above the plant, runoff and other dilution sources made the quality of water in the Illinois vary widely. The deteriorating quality of this water source, and the innumerable produc-

tion complaints it caused, led to the establishment of a sustained basic data program at the glass plant. Simple chemical determinations, originally selected to denote the scaling index by the Langelier formula, were made. These determinations were relevant to various critical production operations. It was soon found expedient to carry on separate programs for individual processes and, in addition to these programs, a comprehensive graph has been maintained throughout the years. A series of charted averages was plotted for operational assistance and future planning. The usual tests for chlorides, sulfates, hardness, pH, total dissolved solids, chlorine demand, turbidity, and alkalinity were made. Local weather data were correlated with the quality data.

The procedure has changed little throughout the years. Although chlorides and sulfates are still checked, they have been dropped from the list of factors regularly plotted, primarily because their variation was strictly a function of dilution. Tests for chlorine demand have been dropped, except for occasional checks, in favor of the simpler flash test. Chlorine demand was also found to be mainly a function of dilution, as indicated by alkalinity. Checks for calcium hardness were added to the procedure.

Figure 1 illustrates one factor measured, the yearly turbidity cycle. A gradual trend of improvement is indicated. It is noteworthy that the cycle was interrupted from December 1956 to February 1957, because of increased diversion from Lake Michigan. It is also noteworthy that extremely high turbidities have become rare. This condition is attributed to a highly efficient US Soil Conservation Service group.

Since the initiation of the data program, plant water treatment facilities—originally crude boiler equipment—have expanded to include modern boiler water conditioning, a cooling-water treatment plant, and a large general process installation that furnishes basic process water for retreatment or adjustment at the point of application. The comprehensive, sustained data, though simple, proved that this water treatment equipment was necessary.

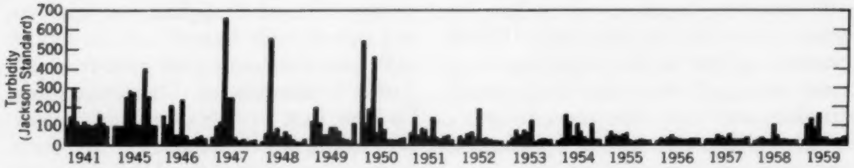

Fig. 1. Turbidity of the Illinois River 1941–59

Tests, made from samples taken at the glass plant near Ottawa, Ill., show seasonal variations. Each bar represents a monthly sample.

Data Needs

To name the types of water quality data that industry needs, one must generalize, because each industry is interested in different parameters. For industry in general every possible parameter is necessary. The basic-data program of the USPHS National Water Quality Network will be of tremendous value to industry. The broad scope of the information, its reliability,

and the indication of trends and ranges will be a boon to industrial planning and engineering.

The automatic instrumentation demanded by industry is being developed to make many analyses.

From the standpoint of many industries and municipal establishments, the greatest current gap in data and analytical procedure is a practical, short, but reasonably accurate method for the determination of pollutant detergents. Even better would be a way to eliminate the pollutant detergents completely. It is a problem of growing intensity and an unknown factor of potentially great importance to many industries.

Recent developments to analyze organic wastes by the US Public Health Service appear to be a good preliminary step, but the equipment used is cumbersome, and the process is too long, tedious, and involved for standard industrial procedure.

Conclusion

During the past few years, most states have either adopted comprehensive pollution control laws or have instituted programs for regulating pollution. Some of these laws and programs are aimed primarily or specifically at industry. Although it is desirable to reduce pollution, drastic pollution legislation at the local level could work to the economic disadvantage of the communities. In view of the advantages of the interstate compact system for basin control, intelligent use of the USPHS basic data program might eliminate some of the confusion and inequities arising from local laws and programs.

The author notes with interest that, in 25 years, he has never experienced a water problem that was traced directly to industrial pollution. The same cannot be said for municipal or agricultural pollution. Admittedly, many industrial applications are not concerned with tastes and odors, so this does not imply that industrial pollution is nonexistent. It is recognized as a serious problem, but not a problem restricted to industry.

It is hoped that the USPHS basic-data program will ultimately result in the establishment of realistic basic stream water standards that can, by actual and not hypothetical control, be made stricter from time to time as industrial and public awareness progresses.

Federal Needs—*K. S. Krause*

A paper presented by K. S. Krause, Chief, Tech. Services Branch Div., Water Supply & Pollution Control, US Dept. of Health, Education and Welfare, Washington, D.C.

The amount of basic data needed for planning and developing water resources in an efficient and coherent manner has increased over the years in a geometric rather than a linear progression. This increasing need is not only for a greater bulk of information, but also for more and more types of data.

When the development of water resources began, information pertaining to navigation was of primary interest. Then the types of data useful in water power development, flood control, water supply, and irrigation were needed. More sophisticated and detailed data about rivers, lakes, and streams were required. Although it took 150 years to achieve the present degree of water resource development, most of the progress has come in the last 35 years. During this 35-year

growth period, basic information requirements have multiplied apace. The need for basic data is demonstrated by the US Bureau of the Budget's estimate that during the years 1961–75 $77,500,000 will be spent for obtaining and processing basic water quality data.

The data needs and uses described below apply, in many instances, to data about water quantity as well as quality. This is because it is difficult to separate water quality from water quantity programs.

The federal agencies having legal responsibilities for collection of basic information for planning, developing, operating, and maintaining water resources projects are numerous. In 1940, the old National Resources Board listed fifteen such agencies; in 1955, the Task Force on Water Resources, Second Hoover Commission, listed 24. These, of course, collect all kinds of information on water resources. Many agencies use water resources information without having the responsibility for collecting it. A review of several reports in which such compilations have been listed indicates that there are 48 federal agencies that use data on basic water quality and associated hydrology. The purposes for which these agencies use water quality data may be grouped roughly in the following categories:

1. Development of supplies
2. Utilization of water resources
3. Monitoring for conformance to standards
4. Quality control
5. Depicting trends in water quality.

Development of Supplies

The role of water quality in water resources planning is being recognized as complementary to quantity. Conservation no longer means merely the control and efficient use of water in the quantitative sense. Agriculture, industry, cities and towns, recreation facilities, and wildlife are dependent on water of satisfactory quality, as well as adequate quantity, if they are to develop during the years to come. As these users have a profound influence—most of it adverse—on the water they use, steps must be taken to reclaim or protect the water, eliminating adverse effects on the next user. The need to foresee and plan the efficient development of water resources, and to control the quality of these resources, is manifest. Such development and control will require a tremendous amount of basic water quality data. The US Army Corps of Engineers, the US Bureau of Reclamation, and the US Soil Conservation Service, as the principal water resource development agencies of the federal government, need information to plan the amount of storage for water supply, and to determine the dilution requirements for natural and man-made pollution control. These agencies want to know the effects of the quality of water on agriculture, potable water supplies, industrial water supplies, fisheries, recreation, wildlife, and navigation. The USPHS, under the Federal Water Pollution Control Act, is initiating a program of comprehensive planning, in cooperation with state and interstate agencies, to control and prevent water pollution. This program will make available to the development agencies some of the answers to the questions they are asking. The needs of the USPHS and cooperating agencies for basic information will be great. The kinds of information needed will include:

1. Comprehensive information on the biologic, bacteriologic, radiologic, chemical, and physical quality of many

supplies at selected points of flow or quality change.

2. Intense time-study information on certain quality parameters from which statistical interpretations, confidence limits, and trends may be established.

3. Continuous quality measurements by automatic instrumentation.

4. Use data—the volume taken out and returned to the stream at each point of use.

In addition, a great deal of information will be needed on the demography of regions—people, agriculture, industry, and resources—to supplement the basic water data. These data will facilitate the construction of mathematical models of rivers or lake basins into which flow and quality variables, combinations, and behavior patterns may be inserted and the dynamics of the waterway may be determined. Such knowledge, plus a program of controlling pollutants at their source to the maximum extent possible, will bring about effective water quality control and promote sound and comprehensive water resources development.

Use of Resources

Users of water resources will be aided by basic quality information in two ways: (1) it will indicate to any prospective user the kind of water which he can reasonably expect to have; and (2) it will indicate to him where and how he must dispose of waste water to minimize pollution and adverse effects on downstream users. An irresponsible attitude toward pollution control can no longer be tolerated.

Conformance to Standards

The third group of consumers of basic information includes the regulatory agencies and the potential polluters who are guided by certain legal requirements, standards, or ranges of quality. Thus the basic data serve as measuring devices. A substantial portion of the total information needed is for this purpose. USPHS, through its interstate pollution abatement enforcement activities, is a great employer of such information. Other federal agencies who may be contributors to pollution are also interested in such information. It serves as an indicator of the sanitary quality of the receiving stream or lake. It also indicates the trends and changes occurring, and the corrective actions that contributors must take.

Quality Control

Quality control is just beginning to be seriously considered, but is certain to have a tremendous future. It offers an intriguing challenge to planners, developers, and operators. Although quality control is by no means limited to federal agencies, the latter will undoubtedly play a significant role in applying basic data to it.

The objective of quality control is to provide, within predetermined limits, a given quality of water. This is important because costs and operating problems of industry, agriculture, recreation, and domestic water treatment are largely associated with fluctuations in water quality.

Quality control can be exercised to some degree wherever streamflow is regulated, but it certainly becomes most effective when pollutants are highly controlled at their source, streamflow is highly regulated, and these two practices are coordinated. Theoretically, by measurement of the amount and pollution characteristics of the incoming wastes, the concentration of pollutant at the points of use can be controlled by flow regulation. The

degree to which exact quality control can become a practical reality is, of course, dependent on the ability to obtain and interpret correctly the quality information needed to build and operate the proper treatment and regulating structures. Those goals will not be attained overnight.

One of the most important steps in achieving this control system is the developing of accurate, useful measuring devices. The instrumentation that will provide continuous and reliable information on background water quality in several indicator parameters must be developed. The correlation of these parameters with stream hydrology and hydraulics will set the stage for a sophisticated system of quality control. This, in turn, will extend the use of water resources in both time and amount, and thus, in effect, increase available water supplies.

The stream-monitoring systems now in use in the Ohio River and lower Mississippi River are forerunners of this instrumentation concept. The US Army Corps of Engineers has the fundamental flow system already worked out for the Columbia River and the Missouri River. Tied in with weather forecasting and past hydrologic records, the flow system can be set up as a statistical problem that a computer can solve. The results are maximum power generation, irrigation, flood control, and navigation use of the stream. On a system for computing hydraulic control of the stream, the quality picture must be superimposed. This, of course, will greatly increase the complexity of the problem, but it does not render the solution impossible. There is a real need for the realization of such a system. Quality, unlike quantity, does not stay within limits set by nature. Water left without quality control measures will become increasingly degraded at an alarming rate. Therefore, increased vigilance must be exercised to prevent degradation from getting entirely out of hand.

Depiction of Quality Trends

The last group of users of basic data is that responsible for providing an appraisal of the trends in water quality. This appraisal is a very great responsibility, as the public health—both physical and economic—is at stake. The public health depends on the ability to measure accurately all aspects of water resources and to translate these measurements into terminology that will give the public adequate information on the quality of streams and lakes. In the author's opinion, efforts to keep the public informed have not been effective enough. To a large extent, quality appraisers rely on indirect and often inadequate methods of measuring the trends and progress in water quality improvement or degradation. The methods of measurement must be greatly increased in number, sensitivity, and kind if an accurate data collection and reporting system is to be obtained. It is not so much a question of duplicating effort among the several agencies gathering basic data as it is of broadening and intensifying these efforts to obtain a clearer view of the whole water quality picture.

Conclusion

It is seen that instrumentation for gathering necessary data on water quality parameters is one of the most important keys to understanding the dynamics of stream quality. With such understanding, a great deal can be accomplished in water quality control.

—Significance of Radioactivity Data—Conrad P. Straub—

A paper presented by Conrad P. Straub, Chief, Radiological Health Research Activities, Division of Radiological Health, R. A. Taft San. Eng. Center, Cincinnati, Ohio.

Since October 1957, the National Water Quality Network, which was instituted by USPHS, has received samples weekly from many points on major watersheds. The network's scientists have analyzed these samples to determine, among other factors, the extent and kinds of radioactivity in United States waters.

The gross radioactivity level of surface water is determined in one analysis.[1] Another analysis separates the suspended solids from the water by passing it through a membrane filter.[2] This study provides information on the effectiveness of common water treatment processes in removing radioactivity.

Extensive data on the levels of radioactivity in the Missouri-Mississippi River basins during the first year of the network's studies were published in 1959.[3] Data on the Sr^{90} levels in surface waters of the United States have also been published.[4]

This article presents radioactivity measurements in surface water samples. It illustrates the kinds of information that may be obtained from such analyses and indicates how the data may be interpreted. By means of selected data presentation, specific parameters of radioactivity measurements are indicated and their significance evaluated.

TABLE 1

Mean Sr^{90} Levels in United States Streams

Period	Sr^{90} Level* $\mu\mu c/l$
Oct.–Dec. 1958	$0.67 \overset{\times}{\div} 2.2$
Jan.–Mar. 1959	$0.91 \overset{\times}{\div} 2.0$
Apr.–Jun. 1959	$1.41 \overset{\times}{\div} 1.7$
Jul.–Sep. 1959	$0.72 \overset{\times}{\div} 1.9$
Oct.–Dec. 1959	$0.62 \overset{\times}{\div} 1.7$
Jan.–Mar. 1960	$0.52 \overset{\times}{\div} 2.0$
Apr.–Jun. 1960	$0.63 \overset{\times}{\div} 1.8$

* Geometric mean $\overset{\times}{\div}$ geometric standard deviation.

Factors Reflected by Data

Table 1 shows Sr^{90} levels in United States surface waters for the period October 1958 through June 1960, by quarters. It will be seen that Sr^{90}

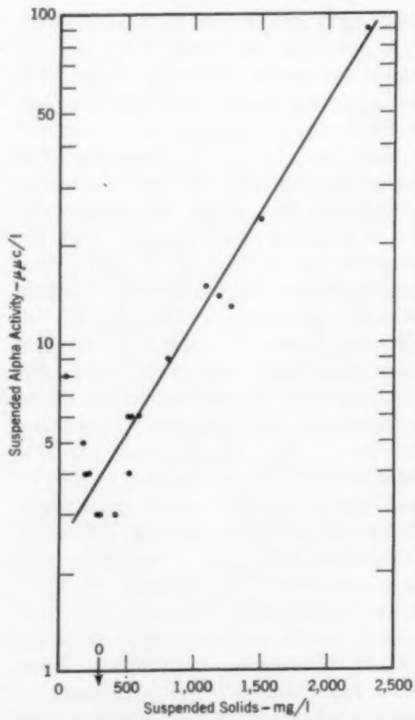

Fig. 1. Alpha Activity and Suspended Solids—Red River

Data are for samples taken at Alexandria, La.

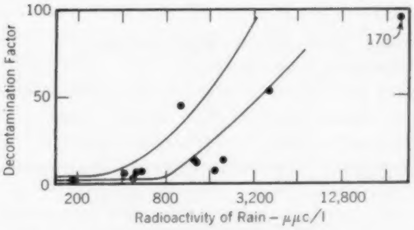

Fig. 2. Decontamination of Rain by Natural Agents

The region between the curves shows the range of 1956 decontamination factors; the dots represent 1957 monthly decontamination factors. The July 1957 rainout of 33,200 μμc/l corroborates the 1956 trend.

content increased for the first three quarters indicated—that is, from October 1958 through June 1959. During the next three quarters, the levels fell and, with the exception of the data for July–September 1959, are all lower than previous values. A slight rise was again indicated for the period April–June 1960 where the geometric mean value increased to 0.63 μμc/l from a previous value of 0.52 μμc/l. The decrease in Sr^{90} levels observed is expected, inasmuch as there have been no weapons tests since October 1958 (with the exception of the French shots in the Sahara Desert). The increase observed for the period April–June 1960 reflects runoff from the snows and rains deposited during the previous quarter when the bulk of the weather normally comes from the North. There is an increase in radioactivity levels with latitude as one moves northward from the equator. The maximum occurs at 40–60 deg north latitude.

Figure 1 shows suspended alpha activity in relation to suspended solids. A rather well defined straight-line relationship is obtained when these two parameters are plotted on semilogarithmic paper. Where rivers flow through uraniferous soils, as does the Red River, the presence of suspended solids containing alpha activity is expected; the relationship shown is therefore not unusual. The network's attempts to obtain similar relationships with beta activity, as at Cincinnati, have been inconclusive, although such a relationship was indicated in data presented by Setter and others.[3] Such a relationship might more reasonably be expected during periods of high radioactive fallout, rather than when radioactivity levels are very low, as they are now.

Decontamination

Where radioactivity levels are known for rainfall as well as surface

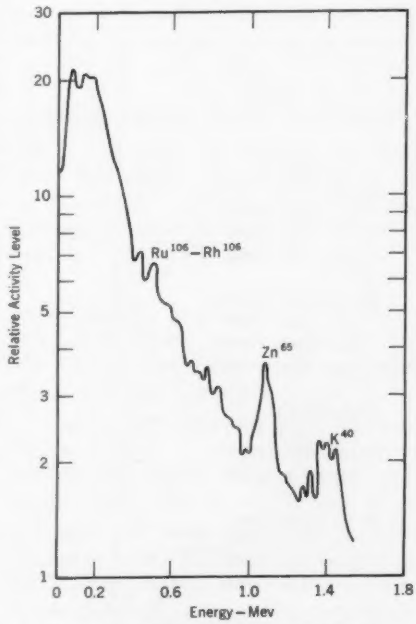

Fig. 3. Gamma Scan—Bonneville and Pasco

Only the man-made radionuclides Zn^{65} and Ru^{106}-Rh^{106} are indicated. This sample was approximately 1 year old.

TABLE 2

Average Gross Alpha and Beta Activity Levels; Suspended and Dissolved Solids Concentrations—Ohio and Columbia River Basins

Station	Alpha—$\mu\mu c/l$				Beta—$\mu\mu c/l$				Solids—*ppm*			
	Suspended		Dissolved		Suspended		Dissolved		Suspended		Dissolved	
	1959	1960*	1959	1960	1959	1960	1959	1960	1959	1960	1959	1960
East Liverpool, Ohio	0.8	0.3	0.3	0.1	17	0	20	1.2	60	12	260	231
Huntington, W. Va.	1.4	2.1	1.0	0.4	32	6.1	31	3.0	86	89	266	218
Cincinnati, Ohio	3.3	2.6	0.2	0.3	23	5.8	16	7.1	138	125	289	230
Evansville, Ind.	1.7	2.0	1.7	0.3	38	7.1	25	1.7	114	157	278	226
Cairo, Ill.	1.1	1.8	0.8	0.9	23	3.5	30	5.7	128	99	272	248
Alsea, Ore.	0.2	0	1.0	0	4.8	1.2	15	1.6	41	18	112	81
Wenatchee, Wash.	0.1	0	0.1	0.4	5.9	0.4	23	9.6	49	16	132	139
Pasco, Wash.	1.4	0	1.2	0.2	61	85	403	428	29	19	137	116
Bonneville, Ore.	0	0.3	0.2	0.5	43	38	205	191	43	25	165	130
Beaver Army Terminal, Ore.	0.1	0.1	0.3	0.3	43	26	141	122	47	28	147	115

* First 6 months of 1960.

TABLE 3

Beta Activity Associated With Suspended and Dissolved Solids—Columbia River Basin

Station	Suspended Solids			Dissolved Solids		
	No. of Samples Studied	Beta Activity $\mu\mu c/l$		No. of Samples Studied	Beta Activity $\mu\mu c/l$	
		Median	Range		Median	Range
Alsea, Ore.						
Jan.–Jun. 1959	18	3	0–52	18	10	0–190
Jul.–Dec. 1959	23	0	0–11	24	0	0–128
Jan.–Jun. 1960	10	0	0–12	10	0	0–16
Wenatchee, Wash.						
Jan.–Jun. 1959	24	6	0–80	24	19	0–286
Jul.–Dec. 1959	24	0	0–10	24	3	0–15
Jan.–Jun. 1960	13	0	0–2	13	0	0–8
Pasco, Wash.						
Jan.–Jun. 1959	26	68	4–207	25	428	80–1,060
Jul.–Dec. 1959	26	47	2–140	26	382	82–817
Jan.–Jun. 1960	25	62	8–560	25	395	133–1,064
Bonneville, Ore.						
Jan.–Jun. 1959	26	50	0–141	26	190	21–486
Jul.–Dec. 1959	18	19	6–86	18	228	73–391
Jan.–Jun. 1960	12	36	8–76	12	168	69–408
Beaver Army Term., Ore.						
Jan.–Jun. 1959	25	57	3–167	24	115	61–347
Jul.–Dec. 1959	22	19	5–71	22	149	51–218
Jan.–Jun. 1960	26	21	8–148	25	75	38–799

waters, removal by natural agents may be related to topographic, hydrologic, geologic, and meteorologic factors. This removal is given in Fig. 2, where radioactivity in rain is plotted against the decontamination factor—that is, the ratio of radioactivity in rainfall to the radioactivity in surface waters.[4] It can be seen that decontamination factors increase with increased radioactivity in rain. This is probably because higher radioactivity levels in rainfall are generally associated with fresh material from weapons tests. The rains contain a high proportion of short-lived radioactive materials that decay rapidly and are readily adsorbed by vegetation or adsorbed and exchanged by soils. Rainfalls that are low in radioactivity generally contain longer-lived materials that are not as readily removed by natural agents, thus accounting for the lower decontamination factors.

Strontium-90 activity in relation to total beta activity and to dissolved beta activity in river waters has been plotted elsewhere.[5] Apparently there is no relationship between the parameters concerned, although a possible correlation between these parameters may be found in lake waters.

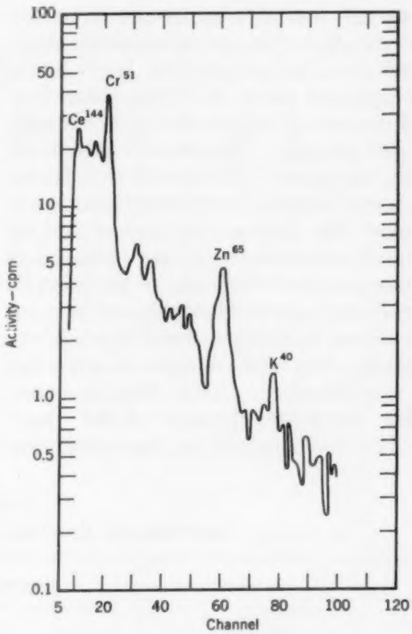

Fig. 4. Gamma Scan of Pasco Water

The sample was collected Mar. 21, 1960. The man-made radionuclides $Ce^{141-144}$, Cr^{51}, and Zn^{65} are prominent. In this sample, the gross beta activity amounted to 949 μμc/l.

Solids and Radioactivity

Table 2 summarizes suspended and dissolved alpha, beta-gamma, and solids levels for 1959 and the first 6 months of 1960 at sample station locations on the Ohio and Columbia River basins. As can be seen, the alpha activity levels are low. Beta activity levels indicated for 1959 are somewhat higher than those reported for 1960, particularly in the Ohio River Basin. This is not true for the lower three stations on the Columbia River—Pasco, Wash.; Bonneville, Ore.; and Beaver Army Terminal, Ore.—which show approximately similar levels for both periods. Solids levels vary somewhat with more variation shown for the Ohio River than for downstream reaches of the Columbia River.

Because the data for 1959 given in Table 2 cover such a wide range of radioactivity levels, these data are presented in Tables 3, 4, 5, and 6 on the basis of three half-year periods: January–June 1959, July–December 1959, and January–June 1960. From Table 3 it will be seen that the radioactivity levels associated with the suspended solids above Pasco were low for even the first period when some fallout reached the streams. The levels increased from Pasco down-

stream, and this increase was caused, certainly, by the operations at Hanford, Wash. The radioactivity levels in the suspended solids at Pasco show little difference in values for the three half-year periods. The second- and third-period values at Bonneville and Beaver Army Terminal were somewhat lower than the first-period values. Low levels of radioactivity are observed in the dissolved fraction in the samples collected above Hanford, but a great increase is indicated for Pasco. These levels drop with distance downstream from Hanford. This drop is caused by the decay of some of the short-lived radionuclides in the water and by the removal of these and other radionuclides by natural agents in the stream environment. Table 4, which gives a similar breakdown of suspended- and dissolved-solids data, shows that the operations at Hanford have little effect upon suspended-solids concentrations observed.

Similar data have been summarized for the five stations located in the Ohio River Basin. As shown in Table 5, radioactivity levels associated with solids fractions showed little variation at these stations. Several nuclear-energy establishments are located in this river basin, but they do not appear to affect the gross-radioactivity concentrations.

TABLE 4

Suspended and Dissolved Solids—Columbia River Basin

Station	Suspended Solids			Dissolved Solids		
	No. of Samples Studied	Solids Concentration *ppm*		No. of Samples Studied	Solids Concentration *ppm*	
		Median	Range		Median	Range
Alsea, Ore.						
Jan.–Jun. 1959	18	20	3–120	18	88	60–524
Jul.–Dec. 1959	23	30	3–230	23	92	40–275
Jan.–Jun. 1960	10	16	8–34	10	77	47–113
Wenatchee, Wash.						
Jan.–Jun. 1959	24	26	9–227	24	138	92–200
Jul.–Dec. 1959	24	22	1–61	24	119	87–276
Jan.–Jun. 1960	13	16	7–28	13	125	95–238
Pasco, Wash.						
Jan.–Jun. 1959	25	26	6–107	25	144	91–328
Jul.–Dec. 1959	26	28	3–59	26	118	20–245
Jan.–Jun. 1960	25	18	6–51	25	112	57–157
Bonneville, Ore.						
Jan.–Jun. 1959	26	32	7–174	26	152	26–304
Jul.–Dec. 1959	18	26	17–57	18	138	106–379
Jan.–Jun. 1960	12	24	6–51	12	133	120–144
Beaver Army Term., Ore.						
Jan.–Jun. 1959	24	32	14–115	24	133	81–399
Jul.–Dec. 1959	22	33	12–60	22	114	43–332
Jan.–Jun. 1960	25	25	8–49	25	117	64–158

Although the difference in suspended-solids levels is somewhat variable, as shown in Table 6, an increase in dissolved solids is observed, particularly for the period January–June 1959. With the exception of the July–December 1959 data for Cairo, Ill., which is low in dissolved solids, all other stations show approximately the same level, 332–375 ppm. The data for the third half-year period are even more uniform; the range of dissolved solids concentration is 207–233 ppm.

Half-Lives of Material

Table 7 shows approximate half-lives of radioactive material found in the Columbia River at Pasco, Bonneville, and Beaver Army Terminal. It will be seen that the range of values is 10–45 days. This would represent a mixture of P^{32}, Cr^{51}, and Zn^{65}, as well as other short-lived radionuclides. Gamma scans of two samples are shown in Fig. 3 and 4. Figure 3 shows the evidence of a prominent Zn^{65} peak and some evidence of Ru^{106}-Rh^{106}. As only Zn^{65} and Ru^{106} were prominent, the age of this material was something in the order of 1 year. Figure 4 shows a gamma scan of a sample that contained 949 $\mu\mu c/l$ of beta activity. Peaks of $Ce^{141-144}$, Cr^{51} and Zn^{65} are prominent.

TABLE 5

Beta Activity Associated With Suspended and Dissolved Solids—Ohio River Basin

Station	Suspended Solids			Dissolved Solids		
	No. of Samples Studied	Beta Activity $\mu\mu c/l$		No. of Samples Studied	Beta Activity $\mu\mu c/l$	
		Median	Range		Median	Range
East Liverpool, Ohio						
Jan.–Jun. 1959	23	29	0–83	23	22	0–92
Jul.–Dec. 1959	16	0	0–20	15	1	0–30
Jan.–Jun. 1960	12	0	0–0	12	0	0–7
Huntington, W. Va.						
Jan.–Jun. 1959	26	35	0–265	26	26	0–328
Jul.–Dec. 1959	25	0	0–40	24	6	0–84
Jan.–Jun. 1960	14	0	0–32	14	0	0–20
Cincinnati, Ohio						
Jan.–Jun. 1959	24	46	0–250	24	22	0–63
Jul.–Dec. 1959	27	1	0–30	27	14	0–62
Jan.–Jun. 1960	14	2	0–39	13	0	0–22
Evansville, Ind.						
Jan.–Jun. 1959	12	28	0–142	12	16	7–80
Jul.–Dec. 1959	2	2	0–5	2	16	13–19
Jan.–Jun. 1960	13	2	0–27	12	2	0–7
Cairo, Ill.						
Jan.–Jun. 1959	26	34	2–139	26	36	0–242
Jul.–Dec. 1959	25	1	0–32	25	3	0–88
Jan.–Jun. 1960	14	1	0–12	13	0	0–33

Total Radioactivity Levels

The radioactivity levels found in the solids fractions of samples from the five stations on the Ohio River for the period January–June 1959 are listed in Table 8 along with average flow values. The total radioactivity in water passing each station can be calculated from these data. These values are included in the last two columns of Table 8 and show that there has been a marked variation in the radioactivity levels associated with the suspended solids fraction in c/day with a general increase from approximately 4 to 27.2 c/day. The radioactivity associated with the dissolved fraction ranged from 3.0 c/day at East Liverpool, Ohio, to 28.8 at Cairo. Substantially constant values in the order of 7 c/day were observed at the three intermediate stations. Radioactivity levels increased markedly in both the suspended- and dissolved-solids fractions in the stretch of river between Evansville, Ind., and Cairo. This increase could have been caused by the radioactivity contributed by the Tennessee River system, which discharges into the Ohio River east of Cairo. The Tennessee River receives wastes from Oak Ridge National Laboratory. Data on radioactiv-

TABLE 6

Suspended and Dissolved Solids—Ohio River Basin

Station	Suspended Solids			Dissolved Solids		
	No. of Samples Studied	Solids Concentration *ppm*		No. of Samples Studied	Solids Concentration *ppm*	
		Median	Range		Median	Range
East Liverpool, Ohio						
Jan.–Jun. 1959	24	56	5–181	24	164	83–508
Jul.–Dec. 1959	15	38	18–155	15	332	61–610
Jan.–Jun. 1960	11	32	13–80	11	233	119–306
Huntington, W. Va.						
Jan.–Jun. 1959	26	82	17–594	26	202	87–380
Jul.–Dec. 1959	25	48	18–232	24	341	78–632
Jan.–Jun. 1960	13	71	17–340	13	207	128–410
Cincinnati, Ohio						
Jan.–Jun. 1959	24	143	32–608	24	204	124–447
Jul.–Dec. 1959	27	68	22–411	27	372	94–975
Jan.–Jun. 1960	13	118	55–187	13	233	175–317
Evansville, Ind.						
Jan.–Jun. 1959	12	90	34–443	12	233	162–423
Jul.–Dec. 1959	2	46	42–49	2	375	366–384
Jan.–Jun. 1960	12	66	26–490	12	224	120–289
Cairo, Ill.						
Jan.–Jun. 1959	26	120	20–1134	26	282	167–632
Jul.–Dec. 1959	25	57	20–366	25	217	97–492
Jan.–Jun. 1960	13	88	10–290	13	230	220–324

TABLE 7

Approximate Half-Lives of Radioactivity Associated With Suspended- and Dissolved-Solids Fractions in the Columbia River

Date	Half-Life—*days*					
	Suspended-Solids Fraction			Dissolved-Solids Fraction		
	Pasco, Wash.	Bonneville, Ore.	Beaver Army Term., Ore.	Pasco, Wash.	Bonneville, Ore.	Beaver Army Term., Ore.
Jan. 12, 1959	23	33	13	14	30	27.5
Jan. 19				23.1		
Jan. 26	31			24.2	24	
Mar. 2	31			18.5		
Mar. 16		33				
Mar. 23	14.7			20	28	
Apr. 27	10			21	36	
May 4	11.6		12	15		
May 11			9.5			10.5
Aug. 10	19			26		
Sep. 8	13					
Oct. 5						33
Oct. 26						28
Nov. 2						27
Nov. 9	26			19	34.5	
Nov. 16						33
Nov. 23	20			25	37.5	
Jan. 4, 1960	24			28.5	32	31
Feb. 23	29		23.3	29	31.5	45.5
Mar. 7			47			
Mar. 14	39.5			26.5		
Mar. 21	19			25.5	24	41.5
Mar. 28	33.5			28		
Apr. 4	16.8			24	33	34

TABLE 8

Radioactivity Load at Various Ohio River Stations—January–June 1959

Station	Activity—*μμc/l*		Flow *cfs*	Activity Passing Station—*c/day*	
	Suspended Fraction	Dissolved Fraction		Suspended Fraction	Dissolved Fraction
E. Liverpool, Ohio	29	22	56,100	4.0	3.0
Huntington, W. Va.	35	26	111,150	9.5	7.0
Cincinnati, Ohio	46	22	137,400	15.4	7.4
Evansville, Ind.	28	16	179,500	12.3	7.0
Cairo, Ill.	34	36	328,000	27.2	28.8

ity levels in wastes released by Oak Ridge have been published by Morgan.[6]

Raw and Finished Water

When the Interstate Quarantine Network is operating, it will be possible to compare radioactivity levels in raw and finished waters and to determine the effectiveness of conventional water treatment processes in removing gross radioactivity. To provide data on this particular subject, some material from reports of the South District Filtration Plant, Chicago, has been extracted. Effectiveness ranging from 13 to 64 per cent for the period January 1958 through January 1960 is indicated in those reports. The average removal value reported was 38 per cent. This demonstrates the ineffectiveness of water treatment processes, even with the extensive treatment provided at Chicago for removal of gross radioactivity.

Discussion

Probability plots have been used to predict radioactivity levels. According to such plots, the peak value of 5 $\mu\mu c/l$ would be expected to occur in approximately 1 per cent of the samples. With the drop in general levels that has taken place since these plots were computed, a value of this magnitude would occur approximately once in 5,000 samples.

With the exception of the values indicated for the Columbia River below Pasco, the highest gross radioactivity in the suspended-solids fraction since July 1959 amounted to 40 $\mu\mu c/l$. The highest dissolved-solids activity during this same period was 128 $\mu\mu c/l$. Because water treatment processes will remove essentially all of the suspended solids and a portion of the dissolved solids, these levels are not high. Of more significance than gross activity are nuclide concentrations, as these must be known if potential hazard from ingestion is to be evaluated.

Many experts have accepted the gross activity value of 100 $\mu\mu c/l$, given by the National Bureau of Standards[7] as a control level. These experts neglected the qualification that this value should be applied for short periods, pending identification of the specific radionuclides that constitute the particular gross-activity level. When such identification has been made, the individual MPC values should be applied for the identified nuclides. In the more recent releases of the National Committee on Radiation Protection,[8] and the International Commission on Radiological Protection,[9] specific MPC's of gross activity are suggested in the absence of the more critical alpha and beta emitters.

Because the alpha activity, the Sr^{90}, and the gross-activity values reported are low, the radioactivity levels encountered, even at the three lower stations on the Columbia River, pose no particular threat to water potability. Radioactivity concentration guides are now under development by the Federal Radiation Council, which has provided no specific numerical recommendations for radioactivity concentration guides yet. Concentration guides now used by the agencies appear appropriate for the time being. Comparisons will have to be made of current environmental levels with values recommended by the radiation committees.[7, 8] The peak value of 5 $\mu\mu c/l$ of Sr^{90} may be compared to an average population MPC value of 33 $\mu\mu c/l$[8] or a maximum level for individuals in special group B.c. of about 100 $\mu\mu c/l$.[8] Thus, current average levels (geometric

mean equals 0.63 $\mu\mu c/l$ Sr^{90}) represent less than 2 per cent of the average permissible population level. It must also be remembered that the permissible levels indicated were arrived at for continuous exposure over a period of 50 years.

Water treatment plants providing coagulation and filtration would remove essentially all of the radioactivity associated with the suspended solids and only a portion of that associated with the dissolved solids. Thus, from the data in Table 8, at least 57 per cent of the activity could be removed at East Liverpool, 57 per cent at Huntington, 67 per cent at Cincinnati, 64 per cent at Evansville, and only 48 per cent at Cairo.

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Instrumentation for Continuous Analysis

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A glance at a text on water analysis, with its long list of constituents and contaminants to be analyzed, is sufficient to give the casual observer some idea of how many needs there are for continuous analyzers. Water may contain contaminants that are toxic, odoriferous, unesthetic, or menacing to human health. The variety and volume of wastes dumped into water sources require that these sources be continuously analyzed so that quality may be constantly maintained for the downstream user.

A number of continuous stream analyzers have already been developed to meet the needs of water management. This article will review the presently available instrumentation, emphasizing the principles involved in the instru-

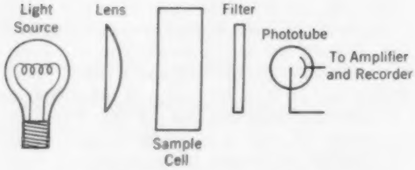

Fig. 1. Elements of a Colorimeter

Colorimetry is used in a wide variety of continuous analyzers.

ments' function, rather than manufacturers or details of design and operation. With the continuing development of new analyzers, it would be impossible for this review to be complete.

Definition

A definition of the terms used in this article would be useful. As this article is primarily concerned with continuous stream analyzers, it would be well to examine the term "analysis." It will refer to the measurement of chemical components in a process stream. Accordingly, the analyzers discussed here are those that measure a characteristic property of chemical materials. Because the term "analysis" implies "how much," an analyzer is an instrument that, by measuring a characteristic property of a chemical material, tells quantitatively the amount of that chemical material in the process stream.

The term "continuous," as used here, includes not only the constant, instantaneous measurement of a property, but also those analyses that require an increment of time for the final measurement to be made. The latter type of analysis is generally regarded as semicontinuous. The criterion used here to consider this type of analysis "continuous" is that the instrument itself automatically and routinely samples the process stream and carries out the analysis at set intervals without intervention from operating personnel.

These two factors, then, give the basic definition: A continuous analyzer is an instrument that quantitatively measures a constituent in a process stream instantaneously or repeatedly without requiring assistance from operating personnel.

It is well known, however, that no instrument will function indefinitely without human assistance. Thus, the terms must be qualified. Should it be assumed that an instrument is continuous if it can run 24 hr without help? Or would a week be a more realistic figure? As any arbitrary figure would be disputable, the qualification must not be a concrete time limit. Three criteria are proposed to replace a time requirement: (1) the instrument operates without attention long enough to justify its existence economically; (2) the instrument does a better job of analysis than is possible by conventional manual techniques; and (3) the

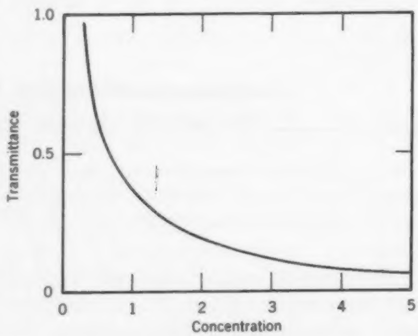

Fig. 2. Light Transmittance and Concentration

In the curve, $T = \frac{I}{I_0} = e^{-abc}$, *where* T *is transmittance,* I *is resultant light intensity,* I_0 *is initial light intensity,* a *is absorption coefficient,* b *is light path length, and* c *is concentration.*

instrument itself can actuate secondary devices continuously to adjust and control process variables, or can activate alarms warning operating personnel of outside-limit conditions.

Finally, to be continuous, the analyzer must be able to function satisfactorily under widely varying conditions. It must be sufficiently rugged to withstand difficulties imposed by the environment, such as temperature, humidity, moisture, shock, and electrical interference.

Applications

Now that a continuous analyzer is defined, some of the applications for such instrumentation may be categorized. Generally speaking, the applications fall into two broad classes: (1) those instruments that assist in water purification and treatment, and (2) those instruments that are used to detect constituents or contaminants in the raw water supply. Some of the commonly analyzed constituents might be mentioned. *Standard Methods*[1] has a list running from acidity to zinc. Some of the more common instrument analyses are for acidity, alkalinity, calcium, chloride, chlorine, color, conductance, fluoride, hardness, iron, oxygen, and turbidity.

With this wide range of analyses, a host of instruments is required to meet the needs of the sanitary engineer. Instruments are in fact being developed almost daily to fulfill these needs. Some of these instruments and the principles they use will be explained.

Colorimetry

Colorimetry is one of the most versatile and widely used principles of analysis. Figure 1 depicts the basic elements of a colorimeter. This discussion of colorimetry will deal primarily with the absorption of visible light. Visual perception of color arises from the selective absorption of certain frequencies of incident light by a colored object. Other frequencies of the incident light are either reflected or transmitted according to the nature of the object. Figure 2 shows the relation between light transmittance and concentration. In chemical analysis, the amount of light transmitted or absorbed by a solution must be measured and related to the concentration of some particular ion or compound in the solution.

With water analysis instruments, this class of analyzers falls into two types. The first is where portions of the stream are passed through the instrument without any pretreatment or chemical addition. Figure 3 shows a typical flow colorimeter installation. Here, the instrument measures directly some quality of the stream. An example of its use is in the monitoring of potable water for color. Color may be caused by the presence of iron or the leaching of vegetable matter. Another important use is in the measurement of turbidity, making the instrument useful in the monitoring and control of coagulation, sedimentation, and filtration processes. The second type of colorimetric instrument might be termed the wet chemical analyzer. Here reagents are added to the sample to produce a measurable property. Although other detecting methods might be employed, colorimetric detection is by far the most widely used. Reagent addition colorimetry can frequently be complex enough to challenge the ingenuity of instrument manufacturers, but this challenge has been met.

Basically, colorimetry is concerned with measuring the amount of light transmitted by a solution. Often, however, many problems must be

overcome before the sample reaches the photometer cell. For example, one or more reagents must often be mixed, perhaps sequentially, with the sample. Frequently heating or cooling is required, and almost always time must be allowed for color development. Precise control of flows or volumes is a necessity. Furthermore, interferences are frequently inherent in the colorimetric method. These are some of the problems facing the instrument manufacturer.

Colorimetric wet chemical analyzers may be further divided into two classes. First is the type of instrument that intermittently samples, and, through stepping switches and programing devices, performs the analysis in much the same manner as the chemist would perform it on the laboratory bench. Figure 4 schematically depicts the principle of such an instrument. This automated "chemist in a box" type of instrument usually measures the sample in a vessel with an overflow leg, measures the reagent or reagents in similar vessels, then permits the sample and reagent to flow through solenoid valves controlled by the programer to a mixing vessel. After mixing and holdup for color development (if necessary), the sample is permitted to flow, again through a solenoid valve controlled by the programer, to the measuring cell. Here transmission of light by the sample at some selected wavelength is related to the concentration of the analyzed component. This type of instrument has been developed to perform even such a complex analysis as that for silica in the trace amounts found in boiler feed-water. As previously noted, the instrument intermittently samples the stream. Hence, the analyses are intermittently performed. This is an example of a semicontinuous analyzer.

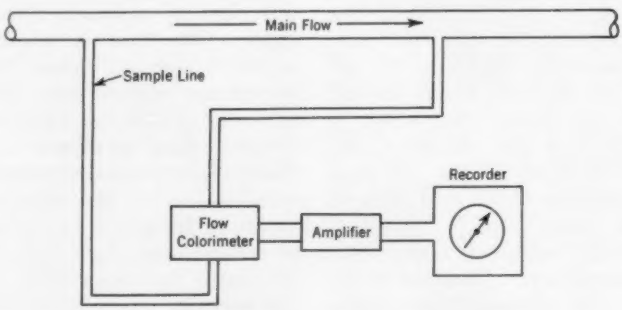

Fig. 3. Typical Flow Colorimeter Installation

In this installation, no reagent is added to the sample.

The second type of wet chemical instrument employing the colorimetric principle is the continuous titrator. Such an instrument relies on a constant and continuous flow of sample to which an indicator solution is also added at constant rate. Figure 5 shows the flow patterns of the titrator. Reagent of constant concentration is added at a rate that varies according to the concentration of the analyzed substance in the stream. The reagent feed rate changes as required to maintain a colorimetric endpoint. Light

transmitted through the solution varies, depending on whether or not sufficient reagent is being added to pass the endpoint of the titration. The signal from the photocell is used to activate continuously a device that increases or decreases the reagent flow rate to make the flow exactly as required to maintain the colorimetric endpoint. Concentration of the substance measured is then related to reagent flow rate.

This type of analyzer can be used only for those analyses that require the addition of a single reagent. Furthermore, color development must be rapid so that no delay time that would cause the instrument to cycle is introduced. In reality, flow is not maintained to meet the endpoint requirements exactly, but the instrument hunts around the flow rate where color change takes place. Colorimetric analyzers are, generally speaking, limited to clean, clear samples.

Some examples of water analysis that use colorimetric analyzers are residual chlorine, fluoride, alkalinity, hardness, cyanide, iron, and chromium.

The development of colorimetric analyzers represents a major trend in instrumentation to meet the needs of those concerned with water and water analysis. Water service operators can look forward to new and perhaps startling developments in this line.

Coulometry

Coulometry is an electrochemical principle that is used in instrument design and consequently in water analyzers. Coulometric instruments are, in essence, continuous titrators wherein the titrating reagent is continuously generated in the quantity demanded by the analyzed constituent in the stream. Figure 6 shows the principles of a coulometric analyzer. Water and nonreactive reagent are caused to flow through an electrolytic cell. Two pairs of electrodes are contained in the cell; one pair serves as a detecting system and the other pair carries an electrolyzing current to generate the reactive reagent. The detecting electrodes transmit information to a controller that transforms this information into appropriate current delivered to the electrolyzers. Generation of reagent is controlled to the exact endpoint of the reaction; thus concentration of the

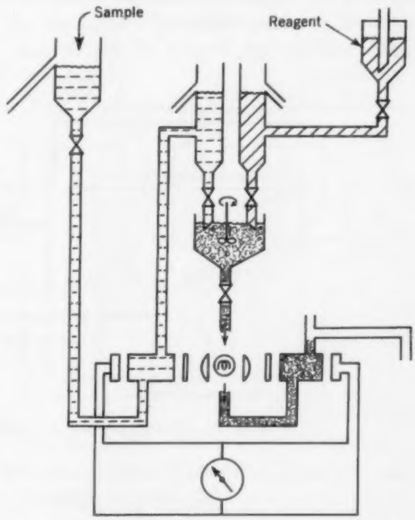

Fig. 4. Semicontinuous Colorimetric Analyzer

This type of instrument is sometimes called the wet chemical analyzer.

reactive constituent is directly proportional to current, based on Faraday's law.

An example of a continuous coulometric titrator is a free-chlorine analyzer.[2] Water with reagent containing ferric ions is caused to flow through the electrolytic cell. Current flow reduces the ferric ion to ferrous ion, which in turn reacts with free chlorine in the sample. Chlorine concentration,

then, is proportional to the current used in generating ferrous ions.

Coulometric titrators are very sensitive devices, capable of detecting changes as small as a few parts per billion.

Amperometry

Instruments for continuous analysis have been developed using the amperometric principle.[3] With these instruments, the chief interest to the water chemist is again residual chlorine analysis. Amperometry employs a fixed voltage on a pair of electrodes. The diffusion current measured at the polarizable electrode is related to the concentration of the substance measured. Figure 7 depicts the flow scheme of an amperometric instrument.

In one commercially available instrument, a potassium iodide and a buffer solution are added to the water sample stream containing the residual chlorine. The chlorine reacts with the potassium iodide, releasing molecular iodine. Depolarizing action of the iodine alters the current flow through the cell in proportion to the iodine concentration. Thus, the amount of current flow is a function of the original chlorine concentration. Readout is on a recorder, and the instrument is said to be able to detect chlorine at about the 0.01 ppm level.

Conductivity

Solutions of electrolytes conduct an electric current by the migration of ions under the influence of an electric field. This phenomenon is used as the basis of another type of continuous analyzer, the electrical conductivity instrument.[4] In a conductivity cell with two plates of fixed area, and with fixed spacing, the resistance to flow of current is dependent on the concentration of ions in the electrolyte between the plates. The resistance depends not only on the total concentration of ions, however, but also on the types of ions. For example, hydrogen ions have roughly seven times the ion mobility (or ion conductance) of sodium ions, and hydroxyl ions have approximately 2.5 times the mobility of chloride ions. It can be seen that electric conductivity measurements are nonspecific with regard to analysis of multicomponent electrolytes.

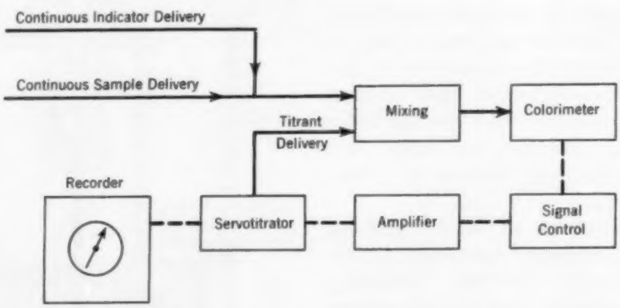

Fig. 5. Principle of a Continuous Colorimetric Titrator

The reagent feed rate is changed with variations of the concentration of the analyzed substance to maintain a colorimetric endpoint.

This discussion does not mean to imply that conductivity instruments cannot be valuable tools for the water analyst. This instrument has been used to follow trends in contamination, and electrical-conductivity measurements have been related to chloride ion concentration in streams. The measurement of total dissolved solids is commonly done by electrical conductivity.

Potentiometry

Potentiometric instruments are common and widely used. The pH meter is an instrument that analyzes the stream for its active hydrogen ion concentration. Once the hydrogen ion concentration is determined, the analyst can easily determine the hydroxide ion concentration from the ion product constant of water. No matter what else may be in the stream, hydrogen ions and hydroxide ions are always present. Their concentrations are of great importance in effecting reactions involving flocculation and sewage digestion.[5] Their presence in proper amounts is essential for the destructive oxidation of cyanide wastes. Their presence can affect taste or promote corrosion in pipes.

The basic components of a pH-measuring system are a glass electrode, a reference electrode, and a highly refined amplifier. These are shown in Fig. 8. The glass electrode responds only to change in hydrogen ion concentration, and this response is marked by a potential change. To complete the circuit, a reference electrode whose potential is unchanged by stream conditions is used. The pH meter amplifies this very weak signal and makes it usable for readout, recording, or control.

A second instrument using the principles of potentiometry is the oxidation-reduction potential (ORP) analyzer.[6] It employs essentially the same principles as the pH meter, as shown in Fig. 9, except that an electron-sensitive electrode replaces the hydrogen ion-sensitive glass electrode. This electrode is generally made of a noble metal such as platinum or gold. This instrument is of particular interest to the water chemist who is concerned with waste disposal. Some of the applications of ORP instrumentation are in the monitoring of streams to detect unwanted industrial-waste reductants or oxidants. Two of the most significant industrial-waste treatments involving ORP are cyanide oxidation and hexavalent chromium reduction process. ORP measurement is also used in sewage treatment processes.[5]

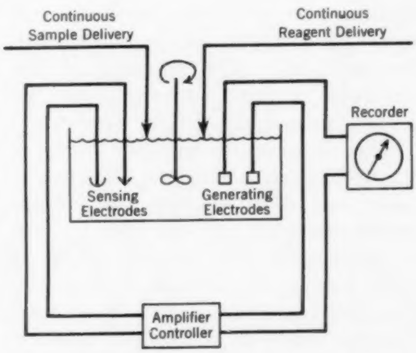

Fig. 6. Instrument Using Coulometric Principle

Generation of reagent by electrodes is controlled to reach endpoint of reaction.

A more recently introduced instrument employing potentiometry is the chloride ion analyzer.[7] It promises to become a valuable tool in water utility operation. As shown in Fig. 10, it uses the same basic equipment as the pH or ORP meter, except that a chloride ion–sensitive electrode is used

rather than a glass or noble metal electrode.

It has long been known that a metal in contact with its ions will produce a potential the size of which will depend on the concentration of the metallic ions. This is simply a form of oxidation-reduction potential in which the metal is the reduced form and the ions are the oxidized form. Thus, if a metal electrode is coated with a sparingly soluble salt containing the anion which is to be measured, the presence of that anion in the stream will control the amount of metallic ions which the metal salt can send into solution, thereby controlling the potential. The potential at the electrode is then determined by the anion concentration in the stream.

The chloride ion–sensitive electrode is made from a mixture of metallic silver and silver chloride salt pressed under extremely high pressure to form a structurally sound billet. This is done because an electrode that is simply coated soon loses its coating through abrasion, erosion, or dissolution when placed in a continuously flowing stream.

Along with the silver-silver billet chloride ion–sensitive electrode, the chloride ion analyzer uses a conven-

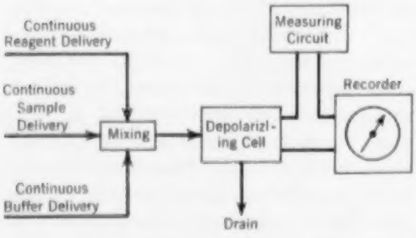

Fig. 7. Instrument Using Amperometric Principle

This type of instrument is useful in analyzing residual chlorine.

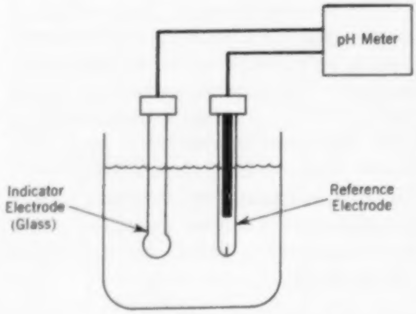

Fig. 8. Basic Apparatus for pH Measurement

At 25°C, $E = E^{o} - 0.0591 \log H^{+}$.

tional reference electrode and a refined, stable amplifier.

Of the many applications of this instrument, there are several which may be of interest to the water analyst. The instrument is being used to monitor rivers for chloride content as an index of stream pollution. It is being used by some industrial plants to monitor or control the disposal of chloride-bearing wastes. An interesting application is that of monitoring sea water intrusion into the delta area east of San Francisco by the California Department of Water Resources.

Like most instruments, the chloride ion analyzer is not completely free from interferences. For example, strong oxidizing or reducing agents interfere. Chemicals that attack silver or silver chloride, of course, cause difficulties, as do those ions which form salts that are less soluble with silver than chloride. Generally, such substances are not found in streams of interest to the water chemist.

Dissolved-Oxygen Analyzer

Dissolved-oxygen content of surface waters is frequently of interest to the water chemist. An instrument has

been developed[8] to measure this factor. The operation of this instrument is based on the fact that at equilibrium, the partial pressure of oxygen above a water surface is proportional to the amount of oxygen dissolved in the water. Figure 11 depicts the flow pattern of a commercial dissolved-oxygen analyzer.

Sample water is pumped into an aspirator where the water is mixed with gas confined in the system. The gas-water mixture is forced into a separator where the gas is separated from the water. Gas is discharged from the separator and flows through a magnetic oxygen analyzer where it is mixed with fresh sample water. The analysis for oxygen itself is based on the well known paramagnetic characteristic of oxygen.

Future Developments

Some instrument developments are taking place that may soon bring water service operators new and important analyzers.

In the field of potentiometry, for example, it appears that more specific ion analyzers may be feasible. Glass

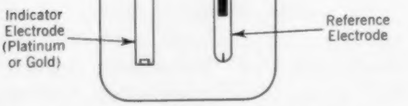

Fig. 9. Basic Apparatus for Oxidation-Reduction Potential Measurement

At 25°C,

$$E = E^{o} - \frac{0.0591}{n} \log \frac{(\text{Reductant})}{(\text{Oxidant})}.$$

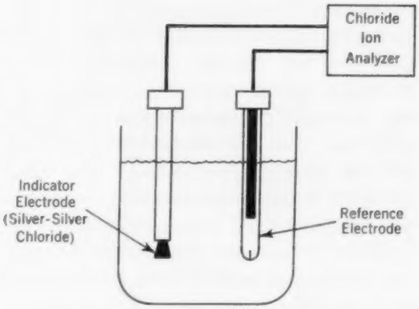

Fig. 10. Basic Apparatus for Chloride Ion Measurement

At 25°C, $E = E^{o} + 0.059 \log (Cl^{-})$.

electrodes have been developed that are sensitive to sodium ion concentration.[9] These electrodes are similar in appearance and construction to pH glass electrodes. Application possibilities for sodium ion analyzers include water softening processes, ion exchange resin technology, and sea water intrusion studies. Other possibilities for specific ion measurement include sulfide, cyanide, and chromate measurement, and these could be useful in treating plating wastes.

Apparently polarographic measurement of dissolved oxygen is almost a practical reality.[10] Such a system was first described by Clark,[11] and the electrode developed is frequently referred to as the Clark electrode. It consists of a probe containing a platinum cathode, a silver anode, and a gas-permeable membrane arranged in a unique manner. Figure 12 diagrams the oxygen electrode system. The platinum surface is pressed firmly against the inside of the membrane, and is electrically connected to the silver anode by a chloride-containing electrolyte which fills the cell. About 0.6 v potential is applied to the cell. The potential is too low to cause dis-

rather than a glass or noble metal electrode.

It has long been known that a metal in contact with its ions will produce a potential the size of which will depend on the concentration of the metallic ions. This is simply a form of oxidation-reduction potential in which the metal is the reduced form and the ions are the oxidized form. Thus, if a metal electrode is coated with a sparingly soluble salt containing the anion which is to be measured, the presence of that anion in the stream will control the amount of metallic ions which the metal salt can send into solution, thereby controlling the potential. The potential at the electrode is then determined by the anion concentration in the stream.

The chloride ion–sensitive electrode is made from a mixture of metallic silver and silver chloride salt pressed under extremely high pressure to form a structurally sound billet. This is done because an electrode that is simply coated soon loses its coating through abrasion, erosion, or dissolution when placed in a continuously flowing stream.

Along with the silver-silver billet chloride ion–sensitive electrode, the chloride ion analyzer uses a conventional reference electrode and a refined, stable amplifier.

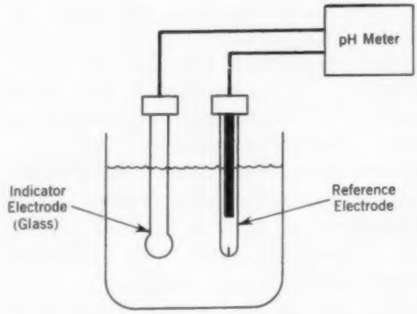

Fig. 8. Basic Apparatus for pH Measurement

At 25°C, $E = E^{o} - 0.0591 \log H^{+}$.

Of the many applications of this instrument, there are several which may be of interest to the water analyst. The instrument is being used to monitor rivers for chloride content as an index of stream pollution. It is being used by some industrial plants to monitor or control the disposal of chloride-bearing wastes. An interesting application is that of monitoring sea water intrusion into the delta area east of San Francisco by the California Department of Water Resources.

Like most instruments, the chloride ion analyzer is not completely free from interferences. For example, strong oxidizing or reducing agents interfere. Chemicals that attack silver or silver chloride, of course, cause difficulties, as do those ions which form salts that are less soluble with silver than chloride. Generally, such substances are not found in streams of interest to the water chemist.

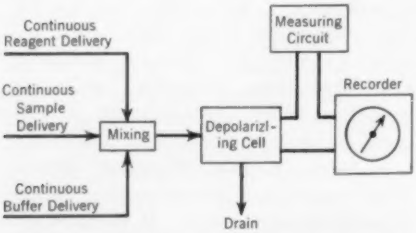

Fig. 7. Instrument Using Amperometric Principle

This type of instrument is useful in analyzing residual chlorine.

Dissolved-Oxygen Analyzer

Dissolved-oxygen content of surface waters is frequently of interest to the water chemist. An instrument has

been developed[8] to measure this factor. The operation of this instrument is based on the fact that at equilibrium, the partial pressure of oxygen above a water surface is proportional to the amount of oxygen dissolved in the water. Figure 11 depicts the flow pattern of a commercial dissolved-oxygen analyzer.

Sample water is pumped into an aspirator where the water is mixed with gas confined in the system. The gas-water mixture is forced into a separator where the gas is separated from the water. Gas is discharged from the separator and flows through a magnetic oxygen analyzer where it is mixed with fresh sample water. The analysis for oxygen itself is based on the well known paramagnetic characteristic of oxygen.

Future Developments

Some instrument developments are taking place that may soon bring water service operators new and important analyzers.

In the field of potentiometry, for example, it appears that more specific ion analyzers may be feasible. Glass

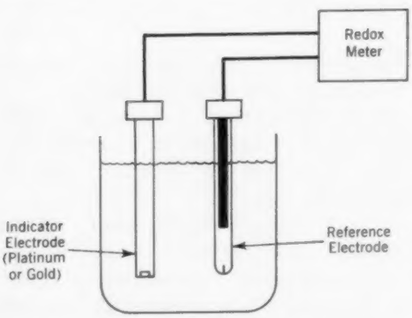

Fig. 9. Basic Apparatus for Oxidation-Reduction Potential Measurement

At 25°C,

$$E = E^o - \frac{0.0591}{n} \log \frac{(\text{Reductant})}{(\text{Oxidant})}.$$

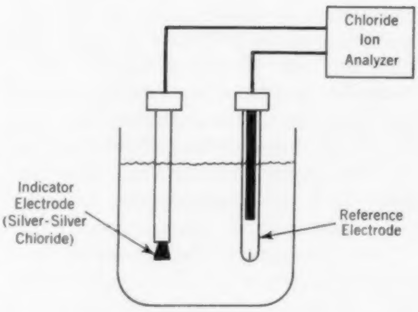

Fig. 10. Basic Apparatus for Chloride Ion Measurement

At 25°C, $E = E^o + 0.059 \log (Cl^-)$.

electrodes have been developed that are sensitive to sodium ion concentration.[9] These electrodes are similar in appearance and construction to pH glass electrodes. Application possibilities for sodium ion analyzers include water softening processes, ion exchange resin technology, and sea water intrusion studies. Other possibilities for specific ion measurement include sulfide, cyanide, and chromate measurement, and these could be useful in treating plating wastes.

Apparently polarographic measurement of dissolved oxygen is almost a practical reality.[10] Such a system was first described by Clark,[11] and the electrode developed is frequently referred to as the Clark electrode. It consists of a probe containing a platinum cathode, a silver anode, and a gas-permeable membrane arranged in a unique manner. Figure 12 diagrams the oxygen electrode system. The platinum surface is pressed firmly against the inside of the membrane, and is electrically connected to the silver anode by a chloride-containing electrolyte which fills the cell. About 0.6 v potential is applied to the cell. The potential is too low to cause dis-

charge of hydrogen and, in the absence of gases reducible at this voltage, the cell merely polarizes. If a reducible gas is present in those passing through the membrane, however, a current flows in the cell proportional to the partial pressure of the gas. Oxygen is the most common reducible gas causing such current flow.

The current can be measured by a microammeter series, by a potentiometer, or most accurately by means of a d-c feedback amplifier. Response time to change in oxygen concentration is quite rapid, and is dependent on membrane thickness and temperature. Current is also dependent on temperature and at present, this limits the usefulness of the electrode. Carritt and Kanwisher [12] report, however, on the use of the polarographic electrode with temperature compensation.

Interesting work has been done using the polarographic technique by Eye and others.[13] They report the use of the polarographic oxygen electrode to be as accurate and reliable as the standard Winkler method in determining dissolved oxygen in BOD samples.

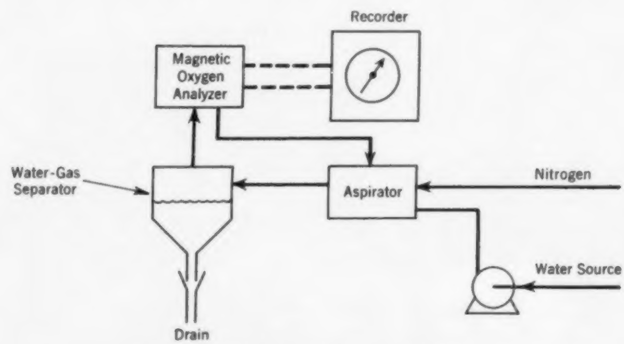

Fig. 11. Dissolved Oxygen Analyzer

This instrument measures the amount of oxygen dissolved in surface waters.

Perhaps the most dramatic developments will be in the field of wet chemical analyzers. Recent trends in the process industries indicate a growing need for analyzers of specific components impossible to identify by some direct chemical or physical property. In this type of analyzer, reagent is added to cause a reaction producing a measurable quality that can be related to the concentration of the desired component in the sample stream. This type of analyzer was mentioned in the discussion of colorimetry. The difference is that here colorimetry is the method of determining the concentration of the reaction product. It can be expected that other principles, such as potentiometry or amperometry, will be used for reaction product determination.

As previously noted, many of the present wet chemical analyzers use semicontinuous, "automated chemist" techniques. Quite complex analyses are made with such instruments. It can be expected that new continuous analyzers will be developed involving even more complex reagent addition systems. Much of the progress in this

field will depend on the development of reliable, precision metering pumps capable of delivering constant flows for long periods of time without much maintenance. Such pumps will have to be capable of pumping not only clean reagents, free of solids, but also samples that may often be considerably less than clean. It appears that considerable progress has been made recently in pump design. Reliable, accurate metering pumps will bring greater simplicity to wet chemical analyzers, and provide new versatility to make possible more complex analyses.

Conclusion

Although a great variety of instrumentation is presently used for continuous water analysis, many analyses are not being made continuously simply because instrumentation is not available. It is probable that some of the complex analyses will be simplified, and some new methods will be developed. This will permit the use of existing types of instrumentation for more analyses. New analyzers will also be developed to carry out more complicated continuous analyses than can presently be done.

A greater understanding is needed for the problems of both the instrument user and the instrument maker. The instrument user wants an analyzer that, once installed, can be plugged in and largely forgotten. The instrument maker would like to provide just such an analyzer. Unfortunately, neither is likely to fulfill this ambition, because many of the constituents of interest to the analyst exist in quantities of a few parts per billion or million, and frequently they are surrounded by a host of interfering substances. Furthermore, the analysis often involves infinitesimally small signals. For example, the current in a pH electrode system may be on the order of 10^{-10} to 10^{-12} amp. Seldom is an analysis free of interference; electronic components are not free from failure; a muddy stream will coat optical cells. As an automobile will not run long without lubrication or tuneup by skilled mechanics, so an instrument expected to do a much more exacting job deserves not only routine maintenance, but an occasional tuneup by a skilled mechanic.

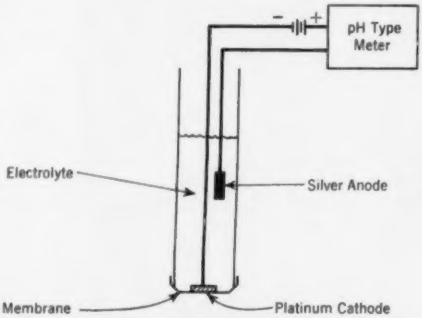

Fig. 12. Polarographic Oxygen Electrode System

Current flow is proportional to the amount of reducible gas passing through the membrane. Oxygen is the most common such gas.

Besides knowing the needs of instrument users, the instrument maker must have the opportunity to realize a profit. He cannot afford to spend vast sums to develop instrumentation for a limited market. For this reason, the most refined instruments available are those that find application in many industries. Instrumentation for pH, infrared, or gas chromatography, for example, is used by many industries. Where special needs arise, cooperative efforts on the part of maker and user could help solve specific problems.

The need and value of continuous stream analyzers for water analysis is obvious. Increased understanding and cooperation on the part of water utility personnel and instrument designers will make possible new and better instrumentation to serve the common good.

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Coatings for Steel Water Storage Tanks

D. W. Christofferson

A contribution to the Journal by D. W. Christofferson, Chicago Bridge & Iron Co., Chicago, Ill.

IN discussing coatings for steel water storage tanks, this article will begin with coatings for inside surfaces and some of the inside coating materials that have been extensively used.

Foremost among the older coatings is red lead–linseed oil paint. Various formulations have appeared continuously in AWWA standards since the early 1940's. The latest is red lead to federal specification TT-P-86a Type I, to which litharge is added at the rate of 2 lb/gal immediately before use.

Over the years, red lead–linseed oil paint has performed reasonably well. Experience shows that when properly used it has more merit than is given it by advocates of the newer synthetic coatings. Service results, however, have been disappointing at times. This fact, together with toxicity questions that have been raised, makes the consideration of other coatings desirable.

Toxicity

The toxicity case against red lead–linseed oil paint does not appear to be well established, in view of the extensive background of use. In the 20 years or so the author's company has used this paint for interior painting, apparently no problem has arisen. Little published technical information is available on the subject other than the articles, "Lead Dissolution From Red Lead Paints in Water"[1] and "Lead Content of Water From Tanks Painted with Red Lead."[2] At any rate, the AWWA Elevated Tank and Standpipe Committee some time ago voted not to include red lead–linseed oil paint for final interior painting in future AWWA standards.

Red lead and oil should not be cast completely aside for several reasons. The first is that it is still one of the most practical coatings for the underside of tank roofs where the surfaces are not immersed. In addition, many tanks now coated with this material may be maintained most economically by continuing with this paint above the water line and below—provided that toxicity is not considered a problem and inspection indicates it has served well. Another reason is that it is one of the few paints considered suitable for application over hand-cleaned surfaces.

Red-Lead Phenolic Paint

Besides red lead–linseed oil paint, various types of phenolic vehicle paints have been used much in the past for new tanks and for repainting old tanks when they have been thoroughly cleaned for repainting by sandblasting. The paint most often used in this category in recent years has been phenolic red lead conforming to Federal Specification TT-P-86a, Type IV. This paint has been listed in the AWWA standard[3] since 1952.

Past experience with phenolic red lead has not been satisfactory, especially when used in a system involving shop priming. On numerous occasions, the paint has not adhered well to thoroughly dry undercoats of the same paint. Similar difficulties have been encountered when primers have been other red leads, including red lead–linseed oil and red lead–alkyd paints. Tests have indicated that even a few days between coats can prove troublesome.

When Type IV phenolic red lead has been applied to bare steel and successive coats have been used, we have experienced trouble with premature blistering and some peeling to bare steel. Surface preparation and application conditions are extremely critical.

Other phenolic paints have given results similar to those experienced with Type IV phenolic red leads. One system consists of lead chromate primer and blue lead–gray enamel phenolic top coats.

Of course, many proprietory as well as government specification phenolic paints have been used in the past, but the phenolic red lead and lead chromate–gray enamel systems will no doubt be declining in use whereas other types of phenolic paints (to be discussed later) will see increased use.

Tar and Asphalt Coatings

Aside from the older types of coatings that are declining in use for interior water tank painting, a number will continue in the future with a certain degree of popularity. Among these are hot-applied coal-tar enamels, cold-applied coal-tar base paints, and wax-type coatings. In addition, asphalt base coatings—although never approved by AWWA standards—have been used often for painting new tanks as well as maintaining old ones.

The coal-tar enamel system has been used far more extensively in the warmer climates than in the Midwest and other colder areas. There is little doubt, however, that hot-applied coal-tar enamel, skillfully applied over a properly cleaned and primed surface, is one of the most water-resistant coatings available. It is not uncommon to find instances of good service for 20 years or more, especially on surfaces where the coating is immersed most of the time. The results generally have not been as good in the area of water level fluctuation. This is especially true in the cold climates; reportedly, this area has also given trouble when not immersed for extended periods in hot weather. Of course, the entire cleaning and application procedure is so critical that inconsistent results may be obtained. In tank work, the coal-tar enamel is applied by hand daubers. Only experienced crews should be used, because application without pinholes in the coating is a problem. Accordingly, a thorough inspection for holidays with an electrical flaw detector is necessary for each square foot.

Cold-applied, tasteless, odorless tar-base paint (commonly called T&O tank solution) is listed in the AWWA standards but, judging by experience, has not been used much in recent years in the Midwest. Even on the West Coast and in the Southeast, where coal-tar coatings are more popular, the T&O solution is used most often above the water level in tanks coated with hot enamel below the water level. Aside from any pros or cons of this material as an interior water tank coating, fume problems have contributed to decreased usage. Most painters

strongly object to applying this material in confined areas. The fumes are very irritating to the skin of many people, and tend to make the painters sick. Accordingly, fresh-air masks and adequate ventilation are necessary for painters.

Cold-applied asphalt coatings, mainly proprietory products, have been used more often for new tanks than have the cold-applied coal-tar paints. Again, certain formulations have shown a tendency to become brittle and to disbond when subjected to cold temperatures and ice in tanks. Therefore, an upswing in the use of asphalt coatings in colder climates is not expected.

Wax Coatings

The wax-type coatings have never been used extensively in new tanks, but experience indicates considerable use in repainting older tanks. Tank inspections in general have indicated reasonably good protection, but as with almost all coatings, there are drawbacks. Being nonhardening, wax-type coatings are subject to abrasion from ice and, between the ice action in the winter and the heat in the summer, the wax tends in time to thin out on the upper shell areas and to accumulate in the tank bottom.

One general drawback to the bituminous and wax-type coatings is that they are completely incompatible with top coats of other types of materials and must be removed entirely in the event a change in paint types is desired. Complete removal is usually more difficult and costly than the removal of most other types of coatings.

Newer Coatings

For the future, indications point to increased use of zinc dust–zinc oxide phenolics, aluminum phenolics, vinyls, and epoxies. In addition, products known as zinc-rich coatings, chlorinated rubbers and even zinc metallizing may become increasingly popular.

A natural question is why zinc dust–zinc oxide phenolic varnish paint should perform better than the Type IV phenolic red lead previously discussed. The answer is that some formulations may not be much better, but other formulations, including Military Specification MIL-P-15145A,* promise to give greatly improved results over other phenolic paints more commonly used in the past. In fact, these zinc dust paints are not especially new; the MIL-P-15145A material, known as Formula 102, was used during World War II on the inside of drinking-water tanks of US Navy ships.

The formula has since been revised, but not radically, and for about the last 6 years this material has been specified and used on the inside of almost all water storage tanks at government institutions and military bases governed by specifications of the US Army Corps of Engineers or the Veterans Administration. One reason, in the author's opinion, for the intercoat adhesion success of the military formulation zinc dust is that the dry film contains considerably more zinc dust pigment and less varnish (on the volume basis) than does the phenolic red lead. In other words, the dry film of zinc dust paint is 60 per cent pigment and 40 per cent varnish; whereas with Type IV phenolic red lead, the ratio is about 40 per cent pigment and 60 per cent varnish. In addition, the zinc dust pigment basically imparts a duller finish with more texture for good

* Also Formula UF-1025 of Bakelite Corp., New York.

bonding of subsequent coats than do most red lead, lead chromate, or blue lead formulations.

All in all, it is likely that the zinc dust–zinc oxide phenolic paint will be as commonly used in the near future as any paints that may be classed in the category of relatively conventional materials. This is one of the few types of phenolic paint considered suitable for shop priming as well as for entire application in the field. In the shop, pickling or blast cleaning is recommended. In the field, blast cleaning should be used for new or existing tanks.

Another phenolic-paint system increasing in popularity is one involving red lead–linseed oil or phenolic red lead primer followed by top coats of aluminum phenolic. It is not certain how much of an improvement this system may be over the straight red lead–phenolic system, but indications are that much better results will be obtained. This system with aluminum top coats over red lead–linseed oil primer may also prove practical for repainting existing tanks now painted with red lead where blast cleaning is not practical. In addition, aluminum phenolic top coats over zinc dust–zinc oxide phenolic primer may develop as a good system.

Vinyl Paints

There is little doubt that vinyl paints are the most proven of the newer types. Vinyl paints have been available for a long time, but have not yet been included in the AWWA standards, as they are expected to be in the future. Application problems, cost, and a lack of service background for these paints have contributed to their limited use in the past. Even now they are used far less than older, more conventional paints.

Two basic types of vinyl systems are used most often. The more common is a system involving a wash primer such as Federal Specification MIL-C-15328A (Ships Formula 117) followed by a prime coat of red lead vinyl per MIL-P-15929A (Ship Formula 119) and at least two additional coats, usually a tinted red lead vinyl and a final coat of aluminum vinyl to Steel Structures Painting Council (SSPC) Formula 8-P-55T or Corps of Engineers Formula V-102. This system is splendid for new tanks involving shop priming where the cleaning is by pickling or sandblasting. The same is true where the complete system is applied in the field to new or existing tanks that need thorough sandblast cleaning. When shop priming with this system, the well seam areas and primer abrasions should be field cleaned by spot blasting.

The wash primer vinyl system yielded excellent results in a large water tank test at Ambridge, Pa., conducted jointly by the Ambridge Water Authority, SSPC, and the builder.[4] The author inspected the test sections that had been immersed 8 years and was favorably impressed. Panel tests have yielded satisfactory results. A number of tanks have been painted with this material, apparently without unsatisfactory results on tank interiors.

When painting with vinyl paints, one must be certain that the entire system is compatible, because there are a number of similar, but slightly different, basic vinyl resins. For example, the red lead vinyl mentioned above utilizes a hydroxyl containing vinyl chloride-acetate copolymer.* Any

* Type VAGH, Bakelite Corp.

vinyl paint formulated predominantly with this type of vinyl resin will not adhere to bare steel, but adheres very well to the wash primer that provides excellent adhesion to bare steel. Another type of vinyl resin (a copolymer of the vinyl chloride-acetate type with 1 per cent interpolymerized dibasic acid)* will not adhere to wash primer but will adhere to bare steel. A third type of vinyl resin (a vinyl-chloride acetate copolymer of average molecular weight)† will not adhere to bare steel or to wash primer and is normally used for vinyl top coats. The various types of vinyl resin paints will adhere satisfactorily to successive coats of the same material or to vinyl paints using the other vinyl resin.

Thus the second type of vinyl paint system eliminates the wash primer and starts out with the VMCH type resin on bare steel. The Bureau of Reclamation uses this type of system, as does the Corps of Engineers at times. A number of proprietory systems are also of this type.

Of course, vinyl paint systems without the wash primer are slightly less costly because the material and application costs for the wash primer have been eliminated. The wash primer system, however, seems to insure slightly better adhesion and to provide a rust-inhibitive coating at the steel surface, which is helpful in the event of water penetration through coating defects.

The drawbacks to the vinyl coatings are that they tend to form extremely thin films unless added application care is used to build up adequate thickness, and that they are generally more difficult to apply than conventional paints.

* Type VMCH, Bakelite Corp.

† Type VYHH, Bakelite Corp.

Spraying is about the only satisfactory application method, and skilled application is necessary to insure films free of pinholes and dry spray. Being extremely fast drying, the paint can readily be deposited as dry spray without adequate adhesion if the spray gun is held too far from the surface.

Vinyl paint systems, of course, are more costly than the paint systems most often used in the past. For instance, even though AWWA standards have always recommended three coats of red lead–linseed oil paint, experience has indicated that, where this type of relatively heavy paint is suitable, two coats are adequate. Thus linseed oil paint requires the application of two or three coats, as compared with three coats of vinyl plus one coat of the wash primer.

Coat for coat, more labor is involved in applying the vinyl paint than in applying the older red leads or the zinc dust–zinc oxide phenolic paints. For instance, Type I red lead–linseed oil has 72 per cent solids by volume; the packaged solids content by volume of the vinyl paints seldom exceeds 25 per cent. In addition, 1–2 gal of special thinner for each 5 gal of paint is normally required for successful application by conventional spray. To deposit an adequate film thickness, it is necessary for the painter to follow a procedure known as cross spraying; that is, to spray a certain area with horizontal strokes overlapping 50 per cent, then to respray the same area with vertical strokes overlapping 50 per cent. At times, additional passes are needed to obtain the desired film thickness.

Application of vinyl paints presents application hazards on interior surfaces. Because of the extremely high

solvent content, painters must wear fresh-air masks. Auxiliary ventilation equipment is needed to keep paint vapor concentration below the explosive limit. In addition to added costs for application, the material costs are at least doubled for each coat because, where a paint coverage of 450–500 sq ft/gal could be obtained with the TT-P-86a Type I red lead, the vinyl paints mentioned normally will not cover over 175 sq ft/gal. Accordingly, when all factors are taken into account for a new tank involving shop priming, a system involving wash primer and three coats of vinyl will cost an estimated 1.5–1.75 times as much as a system involving three coats of red lead–linseed oil or zinc dust–zinc oxide phenolic to federal specification MIL-P-15145A. Where all cleaning and application is in the field, the cost ratio will be somewhat different, as field blasting is a higher percentage of total cost than shop pickling.

Epoxy Resins

Another new type of coating being promoted for interior water tank painting is the epoxy family. This family can be classified into two groups. First is the epoxy ester group, which involves epoxy resin combined with drying oils in much the same manner as conventional exterior alkyd-base finish paints. The other type is the chemically cured type of epoxy wherein a hardening agent must be added to the paint immediately before use.

Experience with both types of epoxy coating is limited in the water works industry. Relatively simple three-coat epoxy ester systems have been applied to both interior and exterior surfaces, as well as chemically cured systems of three to five coats. Such systems and others, including epoxy primers with vinyl top coats, are beginning to show up in specifications, but very little service information is available.

Knowing very well from experience that coatings can neither be condemned nor promoted as a general class, the author cannot predict how suitable these epoxy paints may be. Some manufacturers say they are not particularly recommended for water immersion; many other manufacturers are promoting them for this purpose.

If the epoxy ester paint systems should prove satisfactory, the cost of painting water tank interiors will not be increased greatly, although experience indicates that some paints of this type may increase the overall cleaning and painting costs for new tanks 10–25 per cent.

The chemically cured epoxy coatings present application problems because many have a limited pot life after the catalyst is added. Most specifications for this type of material recommend the application of relatively thick coats. Since drying time or curing time is greatly affected by temperature, these coatings are very slow in drying below 60°F. At temperatures as low as 40°F, curing action is almost stopped.

The only unbiased information available concerning the suitability of epoxy paints for water immersion is the Bureau of Reclamation report P-65.[5] Eight amine-cured and four epoxy-ester commercial epoxy resin materials were tested and reported. In general, the bureau found both classes of epoxy coatings deficient for use in fresh water immersion because of premature blistering. Tests by the Corps of Engineers produced similar results. Both

agencies considered these materials less suitable for water immersion than the vinyl paints now being used. Information received since the tests indicates, however, that use of a polyamide hardener may produce a more water-resistant coating than did the amine hardener.

Chemically cured epoxy systems approximate the cost of vinyl systems. They may be slightly more costly but the added thickness normally used is compensated for by their being higher in solids than the vinyls.

Other Inside Coatings

Chlorinated rubber paints have performed very well in tests, but most of these coatings are more difficult to handle and more costly than conventional paints. A number of water tanks have been coated with proprietary materials, but in general they have not been strongly promoted by many paint manufacturers for painting interiors of steel fresh water tanks. The fact that these paints are prominent for concrete and steel swimming pools indicates their potential for water tank painting.

The final type of interior protection mentioned here involves the use of relatively pure zinc, the purest type being the application of molten zinc with a wire-type metallizing gun. In this process, approximately 10 mils of zinc is recommended, and should be deposited in two or more passes to avoid porosity. Zinc metallizing is not recommended for waters with a pH of less than 6.5, where aluminum metallizing would be employed. Metallizing is very costly initially, and experience is too limited to predict the dependability of a successful application or the service life to be expected.

The other zinc protective systems involve what are known as zinc-rich coatings. These materials are applied cold, much like paint, and are characterized by a high degree of pigmentation approaching 95 per cent of metallic zinc in the dried paint film. The result is a film that acts much like galvanizing in that the zinc particles are in electrical contact with each other and the steel. Thus electrochemical protection is given to exposed steel at a crack or defect in the coating.

Zinc-rich paints or coatings are classed as inorganic when sodium silicate or similar substances are used as the binder, and as organic when chlorinated rubber, epoxy, or other organic vehicles are used as the binder. These coatings, along with metallizing, have had limited use in municipal tanks, but are mentioned because they may well be used more in the future.

Outside Coatings

The inside of the tank presents a more serious maintenance problem than the outside. Exterior painting, though important for protection and appearance, is not as critical.

For exterior painting, good results can normally be obtained with easy-to-use conventional paints. Excellent results have been obtained with a red lead–linseed oil–alkyd primer conforming to Federal Specification TT-P-86A Type II. This paint dries considerably faster than straight red lead–linseed oil paints commonly used in the past, but contains enough free linseed oil to provide good wetting characteristics as well as ease of application. There are many other suitable exterior primers.

For exterior finish painting, aluminum paint has long been a standby and

has yielded excellent results. It is no longer necessary to mix the aluminum paste and vehicle in the field; most aluminum paint used today is ready mixed. This has resulted in much less trouble with initial appearance at no decrease in durability. Experience has been especially good with a ready mixed aluminum using a long-oil varnish vehicle, consisting of cumaroneindene resin, processed with china wood and refined soya bean oil, and reduced with mineral spirits. This and other suitable paints meet with requirements of the federal specifications listed in the current AWWA standard. Faster drying aluminum paints usually create appearance problems if application is by brush.

Colored Paints

As popular as aluminum has been, more and more tanks are being painted in a variety of colors. Most colored paints being used, classed as long-oil alkyd enamels, are available from reputable manufacturers and have been very successful.

A relatively new type of paint for exterior tank painting is colored aluminum. This paint is available in a number of pastel shades and, although requiring careful application for uniform appearance, can be applied successfully by roller and by spray. Brushing is not recommended. Some 3-year-old installations indicate that both good appearance and durability can be expected from proper applications.

Other Types of Outside Paint

Fast-dry aluminum paints that can be applied over conventional undercoats are also available. These fast-dry paints have been used primarily where there is danger of damaging surrounding properties with slower drying, more conventional paints. As with fast drying vinyl paints, which cannot be applied over most older paints, care must be exercised to see that the paint is not deposited as dry spray.

Naturally, many of the coating types previously discussed for inside painting are available for outside service and are occasionally used. In fact, vinyl, epoxy, chlorinated rubber, and other chemical-resistant coatings should be used for unusual chemical exposures. Experience indicates, however, that such coatings are seldom required on the exterior of municipal water storage tanks. The easier-to-use, less costly, standard aluminum paints and the long-oil alkyds are more practical.

Vinyl-alkyd base paints are available and may prove very practical, especially where exteriors have mild chemical exposures. The purpose of these coatings is to use the easy application of alkyds and the chemical resistance of vinyls. Another advantage over straight vinyls is a better chance of compatibility with existing paint films. This could reduce surface preparation costs when such paints are first used for maintenance painting.

Surface Preparation

Nothing is more important than surface preparation for the success of any painting system.

For new tanks, it is highly recommended that all mill scale be completely removed from both inside and outside surfaces. Scale removal is especially important on the inside surfaces, regardless of the coating system used. Removal can be accomplished in the shop by pickling or blast cleaning, and in the field after erection is completed. The latter is normally

more costly than removal in the shop. When mill scale is removed in the shop, the steel should also be shop primed.

After tank erection, all weld seams and other areas unprimed in the shop must be thoroughly cleaned before the field patch coat of paint is applied. Care also must be exercised to see that all contamination is removed from the shop primer.

In repainting old tanks, consideration must be given to existing surface conditions and original surface preparation. If much of the old paint is in good condition, tightly adheres to the steel, and generally has a sound film, it may be left on as long as repainting is done with the same type of paint or other compatible coatings. Hand wire brushing and scraping often suffice to remove blistered and loose paint and rust, if the paint to be applied has good wetting characteristics. Unfortunately, paints with oil vehicles, such as the TT-P-86a Type I red lead, are about the only ones suitable for application to large areas of hand- or power-tool-cleaned steel. Of course, these methods are often adequate for cleaning local areas.

Most of the newer paint types discussed above, if used for repainting existing tanks, would require removal of the older coatings by sandblasting, just as they require blasting or pickling when used on new steel.

Short of sandblasting, it has been found that power sanding is a relatively good way to remove such paint as loose and blistered red lead–linseed oil. This method of cleaning has been used prior to repainting a number of tanks with the zinc dust–zinc oxide phenolic paints. Results comparable to sandblasting are not expected with this method of cleaning, but evidence does indicate reasonably good results at less cost as long as the paint used for repainting has reasonable wetting power. In this category, some proprietary zinc dust formulations and SSPC Formula 5-55T may be superior to the military formula discussed previously as most suitable for shop priming.

Power sanding normally would not be considered in lieu of blasting prior to changing paint types unless the mill scale had previously been removed.

Pickling and Blast Cleaning

In specifying the cleaning for either shop or field, one should spell out what is required. Merely calling for pickling or blast cleaning will not insure proper surface preparation.

Blasting may be anything from "brush blasting" to "white metal blasting." In between is "commercial blasting," which generally is considered to remove all mill scale, rust, paint and other surface contamination, but still leaves a blotchy surface due to traces of the gray oxide binder film between white metal and mill scale. This degree of blasting is adequate for most coating systems and is usually much less costly than "white metal blasting," which some coating manufacturers recommend for special coatings. "White metal blasting" means a uniform gray-white metallic surface color and sometimes is specified to facilitate inspection. In other words, there is less doubt about when the end-point is reached than with the other degrees of blasting.

In addition to the varying degrees of cleanliness by blasting, the degree of surface roughness varies with the size of the abrasive used. Accordingly, the abrasive size should be limited so as to prevent excessive surface

roughness that may be detrimental to adequate paint thickness over the high points. SSPC specifications limit the size of abrasive to that passing a 16-mesh screen.

For shop cleaning, a carefully controlled pickling process is a highly satisfactory means of surface preparation. Generally, it is as acceptable as the higher grades of blasting, and certain processes have some inherent advantages. Immersion pickling provides thorough and complete descaling of new steel. The surfaces, though relatively smooth compared to most blasting, are textured so as to be ideal for painting. In addition, it is well to use immersion in hot dilute phosphoric acid as the final step. This follows sulfuric acid descaling and fresh water rinsing, which are essential for the minimum of suitable pickling processes. The phosphoric bath adds an additional benefit; a thin film of iron phosphate is deposited on the steel. This iron phosphate film generally is recognized as providing excellent adhesion for most types of paints and, in addition, prevents flash rusting should there be a delay before painting. Tank plates, however, are normally painted while still hot from the phosphoric acid bath to eliminate any danger of surface moisture at the time of paint application.

SSPC has issued specifications covering the three grades of blast cleaning as well as pickling. Several processes are covered by the pickling specification SSPC-SP8-52T, including the three-bath sulfuric-phosphoric acid process. In writing specifications for the cleaning of new or existing tankage, one can refer to the SSPC specifications for pickling or blasting as well as for hand and power tool cleaning when they may be appropriate. These specifications cover what is considered current good practice for the various methods and degrees of cleaning.

Cleaning and Painting Costs

Although the cost of cleaning and painting can vary greatly from one system to another and from location to location, the size of the tank, and the condition of the surface (along with the different charges from one contractor to the next for the same job), a few comparative and approximate cost figures might be interesting.

For field work, commercial blasting of flat-bottom tanks will normally run 10–15 cents per square foot. Commercial blasting of elevated tanks will normally run 15–25 cents per square foot. Power brushing or power sanding might run 5–10 cents per square foot, but normally will not produce results comparable to blast cleaning.

For total costs, a 500,000-gal elevated tank to be blast cleaned in the field is assumed. In this case, a three-coat oil, alkyd, or phenolic base system might run 30 cents per square foot, whereas the wash primer plus three-coat vinyl system would likely run 45 cents per square foot. Hot coal-tar enamel usually can be obtained for about 50 cents per square foot and systems of other types of paint will be within this overall range. Zinc metallizing, referred to earlier, would probably cost $1.50 to $2.00 per square foot for field work.

On new work involving shop cleaning, the surface preparation is a lower portion of the total cost, and usually can be reduced 5–10 cents per square foot.

These costs are no more than general averages; they simply give an idea of the cost ratios for different

coating systems. Material costs alone can vary considerably when different manufacturers' proprietary products of the same generic type are used. For instance, excellent high-quality exterior aluminum paint meeting AWWA standards can be purchased in quantity for about $3.50/gal, which is 0.9 cent per square foot per coat when spread at 400 sq ft/gal, although similar paint from other manufacturers may run close to $6.00/gal or 1.5 cents per square foot.

Maintenance

Proper tank maintenance does not require complete sandblasting and repainting every time a tank is painted. Normally, this is only true when the coating system is changed from one type to an incompatible type.

The outside of tanks should require no more than minor local patch priming and one complete coat at regular intervals. Unless desired strictly for appearance reasons, the time to apply a complete new finish coat is when the first tinges of primer start showing through the finish coat. It is difficult to predict the length of time because it will vary from area to area. For estimating purposes, however, one should be able to count on approximately 5 years between coats. Thus, depending on the tank size, the annual exterior maintenance cost should be about 1–2 cents per square foot per year.

On the inside, maintenance required on the underside of the roof should be little or no more than for the outside surfaces. With red lead–linseed oil, paint under the roof and above the water line generally served for an extended time with little more than local cleaning and patching required. Except for cases of severe ice damage, paint usually serves better in the zone of water level fluctuation than on the surfaces that are constantly immersed. On the constantly immersed areas, failure generally appears in the form of blistering, but general repainting is not always necessary at the first sign of blistering. The purpose of the paint is to protect the steel; a blistered paint film still may be giving complete protection. Sometimes the blisters are between coats and not down to bare steel. At any rate, serious corrosion is not a problem as long as paint blisters are intact. Depending on the size, the water, and climate conditions, estimated inside maintenance costs run 2–4 cents per square foot per year.

Inspections

It is very difficult to predict maintenance costs before a tank serves a certain period of time in its own environment. It is difficult also to make general recommendations concerning the best course of action for cleaning and repainting existing tanks. To make the best recommendation for a specific tank, an inspection to determine the condition of the paint is usually in order. It is recommended that all tanks be inspected regularly at intervals of not less than 3–5 years. Such inspections can often be made by qualified water utility personnel. An inspection service is also offered by most tank manufacturers for tanks they build. Reputable inspection agencies or engineering firms also may be able to handle such inspections.

An indication of how well the paint is serving can often be obtained by looking through the roof manhole, and outside deterioration usually is visible before it has progressed too far. For a thorough determination of the conditions of the paint and the metal, how-

ever, it is necessary to have the tank drained completely for the inspection. It also is desirable to flush or clean the excess sediment from the tank.

It is advisable to keep complete records of tank inspections, repairs, and repainting. With regard to painting, a record should be kept of the types of cleaning employed as well as the specific type and number of coats of paint. General terms (such as red lead) that can be obtained in all types of vehicles should be avoided, and if trade name paints are used, the product number should be noted. These records will be of great help in guiding future courses of action.

In tanks where there have been chronic or repeated cases of paint failure, it may be appropriate to divide the tank interior into sections and test a number of the more commonly used paint systems.

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Electrophoretic Studies of Sludge Particles Produced in Lime-Soda Softening

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TWO recent JOURNAL articles reported the results of electrophoretic studies of the flocs produced in the coagulation, with both alum and ferric sulfate, of waters containing clay turbidity [1] and organic color.[2] This article pertains to the results of electrophoretic studies of the particles of calcium carbonate and magnesium hydroxide produced in lime-soda softening. The effects produced by the addition of small dosages of each of four coagulant aids have also been studied.

During 1933, Clark and Price,[3] in their investigation of the role of sodium aluminate in water softening, reported that both calcium carbonate particles and magnesium hydroxide particles bear positive electrical charges relative to the medium. They ascribed the difference between the ease in softening waters containing magnesium salts and the difficulty in softening waters containing little or no magnesium to the hydrophylic properties of the highly hydrated magnesium hydroxide, as compared with the hydrophobic properties of calcium carbonate. Sodium aluminate was shown to affect the amount of magnesium removed and to play no part in increasing the precipitation of calcium carbonate. Seven years later, Larson and Buswell [4] found magnesium hydroxide particles to be positively charged, and calcium carbonate particles to be negatively charged, throughout the entire range of pH values encountered in lime-soda softening. They also found particles of hydrous alumina to be negative at pH values greater than, and positive at pH values less than, 8.2.

In a recent paper, Corsaro and others [5] measured the electrophoretic mobilities of two commercial grades of calcium carbonate having surface areas of 20.4 sq m/g and 2.7 sq m/g, respectively. The particles of both samples, suspended in distilled water, were found to be negatively charged, but both became positively charged after the addition of small amounts of magnesium chloride. The charge on the sample of larger particle size was changed from negative to positive by only 5 ppm magnesium chloride, whereas for charge reversal of the smaller particles a concentration of 63 ppm magnesium chloride was required.

The primary objective of the research herein was to obtain information with respect to the zeta potentials of the colloidal particles of calcium carbonate and magnesium hydroxide throughout the entire pH range of

TABLE 1

Analyses of Synthetic Waters

Constituent	Synthetic Water A	Synthetic Water B
	Concn. of Constituent—*ppm*	
Ca^{++}	80	0
Mg^{++}	0	49
Na^{+}	92	92
HCO_3^{-}	244	244
Cl^{-}	142	142

lime-soda softening, in order that the basic mechanisms of their coagulation may be more fully understood. Since the introduction of synthetic polyelectrolyte coagulant aids in 1952, a number of articles have been published on the application of these aids to water treatment. Unfortunately, most of the research involving the action of these materials has been confined to coagulation with alum or ferric sulfate for the removal of clay turbidity and organic color. Because of widespread interest in the application of polyelectrolyte coagulant aids in water softening, a secondary objective of the research was to study the effects of several coagulant aids on the mobility and coagulation of the particles composing softening sludges.

Materials and Procedures

All the sludges investigated in this study were produced from two synthetic hard waters. Synthetic Water A was prepared from stock solutions of pure $CaCl_2 \cdot 2H_2O$ and $NaHCO_3$. Synthetic Water B was prepared from stock solutions of pure $MgCl_2$ and $NaHCO_3$. The $MgCl_2$ was prepared by dissolving an accurately weighed sample of magnesium metal, 99.99 per cent pure, in excess HCl, evaporating it to dryness, and dissolving the resulting pure salt in distilled water. Each water contained exactly 4 me/l of the respective salts, equivalent to a carbonate hardness, as $CaCO_3$, of 200 ppm. Analyses of the two waters in ionic form are given in Table 1. Waters with any desired ratio of calcium to magnesium were prepared by mixing the calculated volumes of the two synthetic waters. Reagent grade $Ca(OH)_2$ was used in all instances involving the softening of Water A. Reagent grade NaOH was used to soften Water B.

A standard jar test machine, which accommodated six 1,500-ml square glass jars, was used throughout this study. One liter of synthetic water was placed in each of the jars and

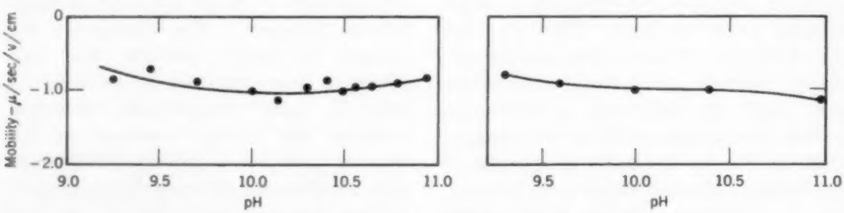

Fig. 1. Effect of pH on Mobility of $CaCO_3$

The curve at the left pertains to $CaCO_3$ sludge produced by softening Water A with varying dosages of lime in the pH range 9.0–11.0. The curve at the right shows the effect of pH on the same sludge suspended in deionized water.

stirred at a paddle speed of 100 rpm while the softening agent was being added. Dosages of $Ca(OH)_2$ were weighed to the nearest milligram on an analytic balance and added rapidly to the jars in a slurry formed by adding about 20 ml of sample water. NaOH was added as accurately measured volumes of a stock solution of known strength.

The test jars were stirred at 100 rpm for a total of 5 min. The paddle speed was then reduced to 40 rpm for 15 min, after which a sample was removed from each jar for particle observation in the electrophoresis cell.

Mobilities were determined in a Briggs microelectrophoresis cell by use of the technique and accessory apparatus described by Pilipovich and others.[6] Because the zeta potential is directly proportional to mobility and because small undeterminable changes will occur in the viscosity and dielectric constant of the medium, particle mobilities will be reported here. An approximate value for the zeta potential may be obtained by multiplying the mobility value by 13.

Effect of pH on $CaCO_3$ Mobility

Figure 1 shows the effect of pH on the mobility of particles of a sludge composed entirely of $CaCO_3$. This sludge was produced by softening Synthetic Water A with varying dosages of lime in the pH range 9.0–11.0. It is evident from Fig. 1 (left) that $CaCO_3$ particles produced by lime softening of a synthetic water of this type were negatively charged throughout the entire pH range usually encountered in water softening.

The results are in agreement with those of Larson and Buswell[4] but in sharp disagreement with those reported by Clark and Price.[3] Although Larson and Buswell reported no mobility values, Corsaro and others,[5] in their studies of $CaCO_3$ suspensions, reported an average mobility value of −1.09 μ/sec/v/cm for a $CaCO_3$ suspension of small particle size, and −1.59 μ/sec/v/cm for a suspension of larger particle size. The values obtained for the sludge particles in this study are in the range of −0.90 to −1.00 μ/sec/v/cm.

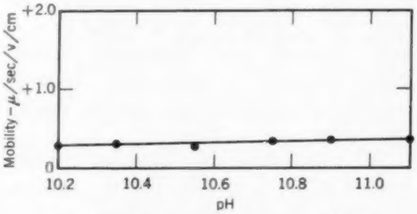

Fig. 2. Effect of pH on Mobility of $Mg(OH)_2$

The relatively constant mobility throughout the pH range shown is probably the result of the protective action of the water molecules surrounding the strongly hydrophilic $Mg(OH)_2$ particles.

Figure 1 (right) shows the effect of pH on the mobility of particles of the same $CaCO_3$ sludge suspended in deionized water. Mobility values were determined under these conditions to evaluate the effect of the various counter ions in the stock synthetic water on the mobility of $CaCO_3$. The $CaCO_3$ sludges were filtered, thoroughly washed, and resuspended in deionized water. The necessary pH range was obtained by adjusting the solution with 0.10*N* NaOH. The values found were essentially the same as those shown in the left-hand portion of Fig. 1. This point will be discussed later in the article.

Effect of pH on $Mg(OH)_2$ Mobility

Particles of $Mg(OH)_2$ were found to be positively charged throughout the pH range 10.2–11.0, as shown in Fig. 2. Pure $Mg(OH)_2$ sludge was obtained by softening Synthetic Water B with varying amounts of NaOH. The relatively constant mobility of approximately +0.50 μ/sec/v/cm over this pH range and at this ionic strength is probably the result of the protective action of the water molecules surrounding the strongly hydrophilic $Mg(OH)_2$ particles. Clark and Price [3] and Larson and Buswell [4] found $Mg(OH)_2$ to be positively charged, but neither reported any specific mobility values.

As most softening sludges contain both $CaCO_3$ and $Mg(OH)_2$, various mixtures of the two synthetic waters were softened with lime to produce sludges whose composition would approximate those produced in softening plants. These mixtures were softened with $Ca(OH)_2$ and the residual magnesium determined by EDTA titration.

The effects of pH on the mobility of the particles produced from softening these mixtures and on magnesium removal are shown in Fig. 3 and 4. A careful analysis of these results reveals several facts. First, electrophoretic measurements showed that particles of both charge types were present in the sludge and that the relative number of negatively charged particles decreased with increasing pH. At the concentrations employed, negative $CaCO_3$ particles could be formed at values less than pH 9.0, but, based on the value of 1.2×10^{-11} for the solubility product of $Mg(OH)_2$, positively charged particles of that compound should begin to appear at pH 10.40. It will be noted, however (Fig. 3, left), that the first positively charged particles were found at about pH 9.9 when only 20 per cent of Water B was used, and at about pH 9.7 when 60 per cent was used (Fig. 4, left). The bottom curves in Fig. 3 show that even at pH values as low as 9.2, approximately 10 per cent of the magnesium ion was removed from solution. This is probably the result, at least in part, of adsorption of the magnesium ion on the surface of the $CaCO_3$ particles, a phenomenon commonly observed in water softening. In fact, it is customary, in calculating the dosage of lime to be used for softening a given water, to assume about 10 per cent magnesium removal by what is usually attributed to adsorption. Adsorption is almost certainly responsible for the presence of positive particles at a pH value lower than that at which $Mg(OH)_2$ precipitates. Second, the mobility of the $CaCO_3$

TABLE 2

Effect of Ca^{++} on Mobility of $Mg(OH)_2$

Lime Dosage *ppm*	pH	Mobility *μ/sec/v/cm*
100	10.40	+1.13
150	10.72	+2.13
200	10.90	+2.50
300	11.20	+1.82
400	11.60	+1.30

TABLE 3

Effect of Added $MgCl_2$ on $CaCO_3$ Mobility at pH 9.8

$MgCl_2$ Concentration *ppm*	Mobility *μ/sec/v/cm*
0	−0.90
50	−0.73
100	+0.97
200	+1.10
250	+1.20

particles decreases, and they become less negative with increasing pH. This behavior is consistent with the assumption that adsorption of the magnesium ion on, or coprecipitation of the ion with, the $CaCO_3$ first lowers and finally reverses the zeta potential of the particles from negative to positive. Throughout this work, some measure of uncertainty was present with regard to the mixtures of the two synthetic waters, as it was very difficult to distinguish in every instance between the two types of particles.

At values greater than pH 10.3, practically all flocs are positive, and the increased positive charge of the $Mg(OH)_2$ formed in the presence of calcium ion is probably owing to the adsorption of this ion. To verify this, a new synthetic water was made, with the same total hardness as $CaCO_3$ but containing only magnesium noncarbonate hardness. $Mg(OH)_2$ was precipitated from 1-liter samples of this water with excess lime. As shown in Table 2, the soluble calcium ion formed in the reaction produced a marked increase in the positive mobility of the $Mg(OH)_2$ floc. The flocs reached a maximum positive mobility at about pH 10.90, corresponding to a lime dosage of approximately 200 ppm, or an excess of about 50 ppm over the stoichiometric value. From this point, the floc particles become less positive, which may be owing to the repressive effect of excess calcium ions on the

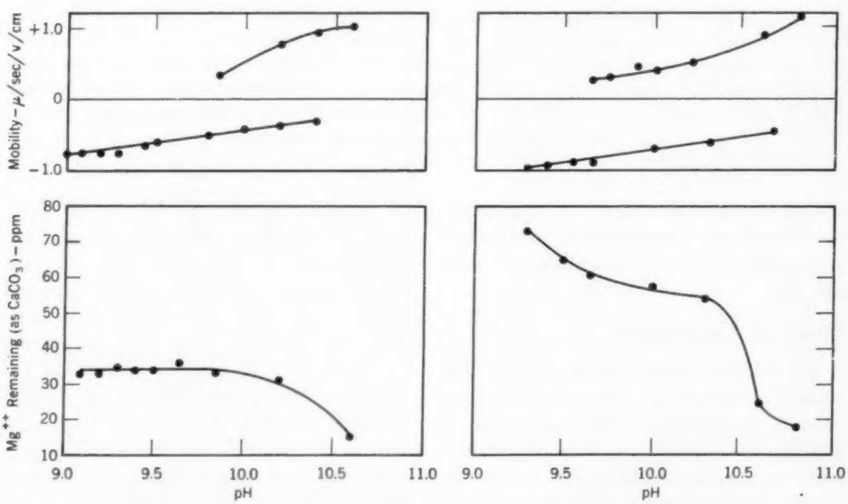

Fig. 3. Mobility of Particles of $CaCO_3$ and $Mg(OH)_2$

The curves at the left resulted when the water softened was composed of 80 per cent Water A and 20 per cent Water B, and contained 160 ppm of calcium hardness and 40 ppm of magnesium hardness, both expressed as $CaCO_3$. The curves at the right resulted when the water softened was composed of 60 per cent Water A and 40 per cent Water B, and contained 120 ppm of calcium hardness and 80 ppm of magnesium hardness, both expressed as $CaCO_3$.

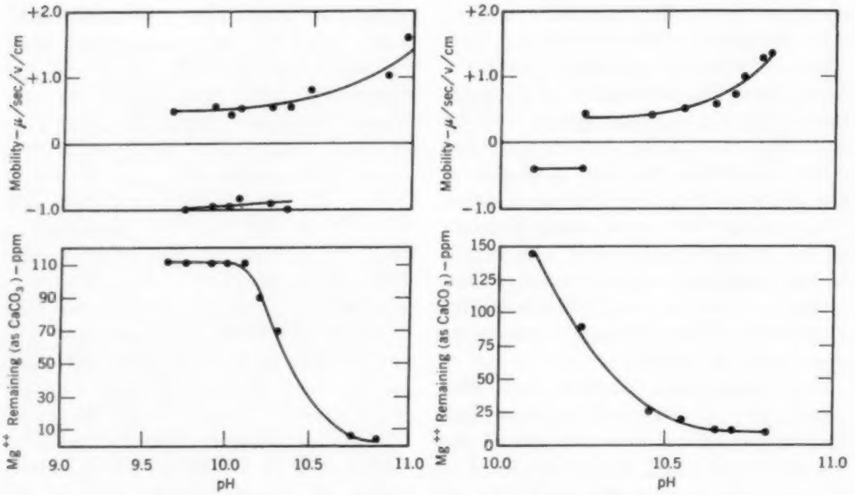

Fig. 4. Mobility of Particles of $CaCO_3$ and $Mg(OH)_2$

The curves at the left resulted when the water softened was composed of 40 per cent Water A and 60 per cent Water B, and contained 80 ppm of calcium hardness and 120 ppm of magnesium hardness, both expressed as $CaCO_3$. The curves at the right resulted when the water softened was composed of 20 per cent Water A and 80 per cent Water B, and contained 40 ppm of calcium hardness and 160 ppm of magnesium hardness, both expressed as $CaCO_3$.

double layer, adsorption of hydroxide ions—such as occurs with both alum and ferric flocs—or a combination of the two.

Effect of Electrolytes

Up to this point in the study, any effects produced by the magnesium ion on the mobility of the particles of $CaCO_3$ have been ascribed to adsorption or coprecipitation, as in all instances magnesium ion was present in the solution as precipitation took place. In order to discover whether magnesium ion is capable of affecting the mobility of preformed particles of $CaCO_3$, the following experiment was performed. Sufficient lime was added to six 1-liter samples of Water A to produce a pH of 9.8 in all jars. $MgCl_2$ was then added to the $CaCO_3$ suspensions 3 min after the addition of the lime. Stirring was continued for 25 min, after which floc mobilities were determined. The data are shown in Table 3. It can be seen that increasing the concentration of $MgCl_2$ brought about a decrease in the negative zeta potential on the $CaCO_3$ particles until, at a concentration of about 80 ppm $MgCl_2$, the mobility and hence the zeta potential were zero. In the presence of more than 80 ppm $MgCl_2$, the particles of $CaCO_3$ became increasingly more positive. In general, these results are consistent with those of Corsaro and others.[5] The dependence of the amount of $MgCl_2$ required

for charge reversal on particle size is evident from their investigation. A concentration of only 5 ppm $MgCl_2$ reversed the charge from negative to positive on a sample of $CaCO_3$ of relatively large particle size. For charge reversal of a $CaCO_3$ suspension of smaller particle size, 60 ppm $MgCl_2$ was required. These results indicate that the magnesium ion is adsorbed on the surface of the $CaCO_3$ particles, thereby lowering or reversing the zeta potentials and the corresponding mobility values.

The effect of $Al_2(SO_4)_3$ and $AlCl_3$ on $CaCO_3$ mobility is shown in Fig. 5. At these pH values, all of the aluminum is present as aluminate ion, and it brought about a slight repression of the zeta potential of $CaCO_3$. The $Al_2(SO_4)_3$ was slightly more effective than the $AlCl_3$ in repressing the particle zeta potential, because of the bivalent sulfate ions present.

The effect of sulfate ion on the mobility of $CaCO_3$ is shown in Table 4. The presence of small concentrations of sulfate ion first increased the negative zeta potential of the particles of $CaCO_3$, reached a maximum at approximately 5.0 ppm of sulfate ion, and then began to decrease at higher concentrations. The presence of large concentrations of sulfate ion probably causes a contraction of the double layer around the $CaCO_3$ particles, resulting in a corresponding decrease in the mobility value. It is probably this effect that accounts for the observed fact (Fig. 1) that the mobilities of $CaCO_3$ suspensions in Synthetic Water A and in deionized water were found to be the same.

TABLE 4

Mobility of $CaCO_3$ in Na_2SO_4 Solutions

SO_4^{--} Concentration *ppm*	Mobility *μ/sec/v/cm*
0.0	−0.88
0.5	−0.89
1.0	−0.95
5.0	−1.58
10.0	−1.26
30.0	−1.52
100.0	−0.98

TABLE 5

Mobility of $CaCO_3$ in $MgCl_2$ Solutions Containing $(NaPO_3)_6$

$MgCl_2$ Concentration *ppm*	Mobility—*μ/sec/v/cm*			
	No $(NaPO_3)_6$	2 ppm $(NaPO_3)_6$	5 ppm $(NaPO_3)_6$	10 ppm $(NaPO_3)_6$
0	−0.88	−1.38	−1.47	−1.74
50	−0.73	−1.00	−1.11	−1.30
100	+0.97	−0.95	−1.10	−1.05
200	+1.10	−0.85	−0.93	−0.98
300	+1.22	−0.74	−0.86	−0.94

Threshold treatment with sodium hexametaphosphate, $(NaPO_3)_6$, has found extensive application for the stabilization of waters that tend to deposit $CaCO_3$ on filter media and throughout distribution systems after lime and lime-soda softening.[7-9] Accordingly, it was decided to repeat Corsaro's experiment, in which he counteracted the effect of increasing dosages of magnesium ion on the zeta potential of a $CaCO_3$ suspension by the addition of increasing dosages of $(NaPO_3)_6$. The data are shown in Table 5. It will be noted that even 2 ppm $(NaPO_3)_6$ is sufficient to overcome the effect of 300 ppm $MgCl_2$. As in stabilization practice much lower dosages of polyphosphates are found to be effective, a second series of determinations of the mobility of $CaCO_3$ particles in the presence of fractional dosages of $(NaPO_3)_6$ was made. No $MgCl_2$ was used. The data are shown in Table 6 and indicate that an increase in the negative zeta potential

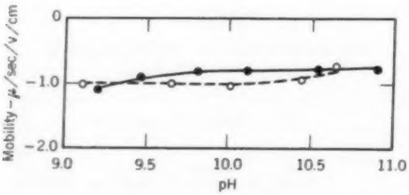

Fig. 5. Effect of $AlCl_3$ and $Al_2(SO_4)_3$ on $CaCO_3$ Mobility

Open circles represent $AlCl_3$; solid circles, $Al_2(SO_4)_3$. The concentration of each chemical was 17 ppm.

of the $CaCO_3$ particles is measurable and significant at these very low dosages. Corsaro and others [5] used similar data to explain the stabilization of high-pH waters with polyphosphates.

Effect of Coagulant Aids

The majority of the coagulant aids used in this study were added to the suspensions during stirring, 2 min after the addition of lime. With regard to activated silica, addition both before and after lime was studied. All mobility and turbidity values reported in this portion of the study were determined at a constant pH of 9.8. Residual turbidity readings were plotted below the mobility curves in order that the relative effectiveness of each coagulant aid might be evaluated. All turbidity determinations were made on a photoelectric colorimeter.* The percentage transmission readings obtained from the colorimeter were converted to the more standard "ppm turbidity" units by calibration of the instrument against a Jackson candle turbidimeter. Samples for turbidity determination were taken directly from the jars, with a sampling device similar to that of Cohen's,[10] exactly 10 min after stirring was stopped.

Aid A.† Figure 6 shows the effect of Aid A, prepared by the "Baylis sol" method,[11] on the mobility and coagulation of a sludge produced by softening Synthetic Water A. In this instance, the silica was added before the lime. It can be seen from the figure that all concentrations of activated silica produced good coagulation. It should be noted that in all instances coagulation was accompanied by an increase in the negative zeta potential of $CaCO_3$. Dosages of less than 1.0 ppm SiO_2 produced a rather sharp increase in this negative charge; the best coagulation was obtained at a SiO_2 dosage of 1.0 ppm. The greatest effect on the zeta potential and coagulation of $CaCO_3$ was produced by minute concentrations of this aid. It is evident that the mechanism of coagulation may not be ascribed to simple charge neutralization and zeta potential reduction of normally negative $CaCO_3$ particles, as activated silica is itself negatively charged.

Black [12] and others have noted that, in some instances, in order to allow for observation of the dramatic effect of activated silica on the coagulation of softening sludges, the aid must be

TABLE 6

Effect of $(NaPO_3)_6$ on Mobility of $CaCO_3$ Particles at pH 9.8

$(NaPO_3)_6$ Concentration *ppm*	Mobility *μ/sec/v/cm*
0.1	−0.90
0.2	−0.95
0.4	−1.26
0.6	−1.31
0.8	−1.35
1.0	−1.40

* The instrument used was a Model 450 Lumetron colorimeter, manufactured by Photovolt Corp., New York, N.Y.

† N Brand Silica, manufactured by Philadelphia Quartz Co., Philadelphia, Pa.

TABLE 7

*Effect of Activated Silica on Mobility and Coagulation of $CaCO_3$**

SiO_2 Concentration *ppm*	Mobility *μ/sec/v/cm*	Turbidity *ppm*
0.2	−1.26	45
0.4	−1.24	42
0.6	−1.25	40
0.8	−1.20	36
1.0	−1.20	34
3.0	−1.23	31
5.0	−1.19	30

* Silica added after lime.

added before the lime. This is indicated by the data in Table 7, which shows the effect of activated silica added after the lime. Coagulation under these circumstances is not as effective as when the silica is added before the lime. The $CaCO_3$ mobility, although it is again more negative than it is in the absence of silica, does not exhibit a large increase in the lower concentration ranges.

As the effectiveness of coagulation with activated silica seems to depend on the distribution of Aid A through the solution before the formation of solid $CaCO_3$ nuclei, it seems probable that a contributing factor to the coagulation mechanism is the adsorption, or at least strong attraction, of calcium ions to the surface of the negative colloidal silica particles and micelles present in suspension. Such an assumption allows for the formation of large floc particles with a maximum amount of interparticle bridging. This effect cannot be produced to the same extent when the activated silica particles are added to a solution already containing $CaCO_3$ nuclei.

Activated silica is employed by a number of Florida softening plants as the sole coagulant. It has long been recognized that its effectiveness is greatly increased as the pH is raised to values corresponding to substantial excesses of lime over the stoichiometric requirement. In this instance, again, calcium ion would be available for adsorption and interparticle bridging.

*Aid B.** Aid B is described [13] as an acrylamide-type, high-molecular-weight synthetic polymer. It is anionic. Figure 7 (left) shows the effect of Aid B on the mobility and coagulation of a sludge produced by softening Water A. As before, the presence of 17 ppm alum resulted in a slight repression of the zeta potential. Best coagulation took place at dosages of less than 0.1 ppm and before the sharp increase of negative mobility produced by higher dosages.

Aid C (potato starch). The effect of Aid C, which is nonionic, on the

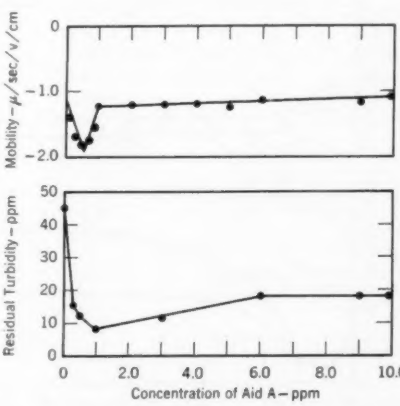

Fig. 6. Effect of Aid A on Mobility and Coagulation of $CaCO_3$ at pH 9.8

This anionic aid was added before the lime. Coagulation was accompanied by an increase in negative charge on the floc particles.

* Separan NP10, made by Dow Chemical Co., Midland, Mich.

mobility and coagulation of $CaCO_3$ is shown in Fig. 7 (right). It can be seen that fair coagulation was obtained with low dosages, and the mobility values of the sludge particles were not affected.

*Aid D.** Aid D is described as an organic polymer of high molecular weight.[14] It is cationic. Figure 8 shows the results obtained with this aid. Fair coagulation was obtained with Aid D at a dosage of 1.0 ppm. In this instance, coagulation was accompanied by a reversal of charge on the $CaCO_3$ particles.

One fact stands out very clearly when these results are analyzed: the mobility value in itself is not a reliable indication of the degree of coagulation to be expected with the use of a coagulant aid and softening sludges. Although coagulation of $CaCO_3$ may

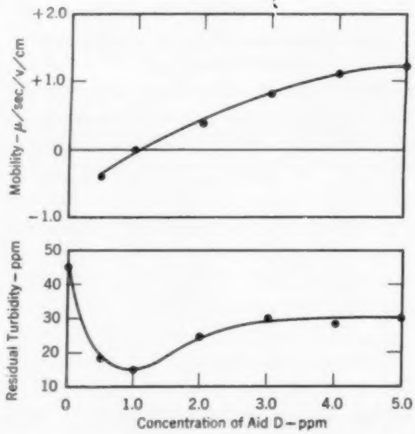

Fig. 8. Effect of Aid D on Mobility and Coagulation of $CaCO_3$ at pH 9.8

This cationic aid was added after the lime. Coagulation was accompanied by charge reversal.

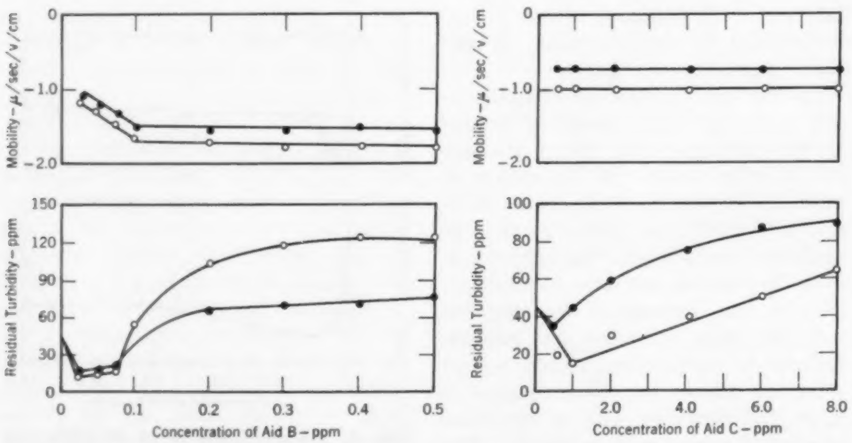

Fig. 7. Effect of Aids B and C on Mobility and Coagulation of $CaCO_3$ at pH 9.8

Open circles indicate that no alum was present; solid circles, that 17 ppm alum was present. Aid B, an anionic aid (curves at the left), was added after the lime. Coagulation was accompanied by an increase in the negative charge on the floc particles. Aid C, a nonionic aid (curves at the right), was also added after the lime. The zeta potential of the floc particles was unaffected.

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* Nalco 600, made by Nalco Chemical Co., Chicago, Ill.

sometimes be accompanied by either an increase or a decrease in the negative charge, the best coagulation was usually obtained at substantially negative mobility values.

Summary

The electrophoretic mobilities of the particles of $CaCO_3$ and $Mg(OH)_2$ formed by softening various combinations of two synthetic waters with lime were measured. The zeta potential of $Mg(OH)_2$ was found to be positive throughout the entire pH range encountered in lime-soda softening. The zeta potential of the particles of $CaCO_3$ was found to be negative in the absence of magnesium, but the potential became less negative and finally became positive as the ratio of magnesium to calcium in the water being softened was increased. The zeta potential of the negative $CaCO_3$ particles was also reversed to positive values by the addition of $MgCl_2$ after softening.

Ions present in the water being softened, and particularly multivalent ions, will affect the zeta potential of floc particles. For example, increasing concentrations of sulfate ion first increased and then decreased the zeta potential of negatively charged particles of $CaCO_3$. Corsaro's work,[5] showing the effect of $(NaPO_3)_6$ on the zeta potential of $CaCO_3$ particles, has been confirmed and extended to demonstrate the effect in the very low dosages normally employed for water stabilization.

The effects of four coagulant aids on floc mobility, coagulation, and settling were studied. The anionic aids were found, as would be expected, to increase the negative zeta potential of $CaCO_3$ floc particles, whereas cationic aids had the opposite effect, reducing and finally reversing the zeta potential of $CaCO_3$ particles from negative to positive. The nonionic aid studied had no effect on particle mobilities and little effect on coagulation and settling.

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Notes and Comment

Nematodes in the Merrimack River

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During the latter part of February 1960, considerable publicity was given to the "nematode problem" in public water supplies.[1-3] As a result, a nematode survey was initiated at the Lawrence (Mass.) Experiment Station in cooperation with the Lawrence Water Department. The latter agreed to furnish the station daily with 1 gal of water from the Merrimack River, which is its source of supply, and 1 gal of finished water. This finished water is the result of the following treatment: rough and fine screening, prechlorination, coagulation with alum, mixing, settling, rapid sand filtration, pH control with lime, aeration, and postchlorination.

As low nematode population was expected, it was necessary to concentrate 1 gal of sample. Because of the gross amount of amorphous material and algae in the raw water, however, the membrane fiber technique proved unfeasible, and it was therefore necessary to employ the Sedgwick-Rafter method.[4] This concentrate was then scanned under low power (100×) with a microscope. The number of nematodes per gallon was recorded. Only adult worms were counted.

TABLE 1

*Nematodes in Raw Water Samples, February–August, 1960**

Month 1960	Samples Examined	Samples Containing Indicated Numbers of Nematodes						
		0	1	2	3	4	5	6
Feb.	4	1	1	1	1	0	0	0
Mar.	22	15	1	1	5	0	0	0
Apr.	19	10	4	2	3	0	0	0
May	16	7	5	1	3	0	0	0
Jun.	20	1	6	4	4	1	3	1
Jul.	16	2	0	0	3	4	4	3
Aug.	3	0	0	0	1	0	2	0

* No nematodes were found in finished water, although each month an equal number of samples of finished water was tested.

Table 1 summarizes the data obtained since the study was undertaken. Definite trends can be discovered. During the summer months a larger proportion of raw samples contained nematodes, and also during these months there was a larger number of samples with more than one nematode per gallon. In all instances, no nematodes could be found in the finished water.

Acknowledgment

The author wishes to thank Joseph C. Derby, senior chemist in charge of the Lawrence Filtration Plant, for his cooperation in this study and in furnishing the station with daily samples.

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Nomenclature for Referring to Organic Extracts Obtained From Carbon With Chloroform or Other Solvents

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As the organic material recovered from carbon filters is being referred to in the literature and is under consideration for a USPHS drinking water standard, it would be well to arrive at a uniform designation to describe the extracts obtained. The present description, which has usually been "chloroform soluble carbon filter extract" (CSCFE), is unsatisfactory.

Several factors have been taken into account in consideration of the proper terminology. The technique of using carbon has been commonly referred to as the "carbon filter technique." Although this is a convenient term, it is not altogether accurate, as the operation performed is not really based on filtration but on adsorption. In addition, the general operation of the unit is in an upflow direction, which is the reverse of the flow direction in most common filtration operations.

In describing materials recovered from carbon, it would be well to drop the term "filter" and refer to the materials recovered in the simplest language that would describe the sample procedure and type of material recovered. It is believed necessary that the term "carbon" be used in the terminology, because carbon is the material used in the sampling. It is further believed that the materials ultimately recovered by the organic solvents are most aptly referred to as "extracts," because the procedure for recovering them is actually done with the laboratory extractor. It is proposed that materials recovered from carbon by chloroform with the techniques described in the literature simply be referred to as "carbon chloroform extract," which would be abbreviated "CCE." The alcohol extract would be called "carbon alcohol extract" (CAE). The sampling technique could be aptly described as the "carbon adsorption method" (CAM). It is recommended that future references to these materials utilize the foregoing terminology.

CHAPTER 4

Manufacture and Test

AWWA Steel Pipe Committee Report

A report on design and installation of steel water pipe has been prepared by AWWA Committee 8310D—Steel Pipe. The report is being published in installments (May 1961 issue, p. 632); comment and discussion by readers are encouraged. Discussion should be addressed to the Editor of the JOURNAL.

As noted in the previous chapter, the pipe permitted under the AWWA steel pipe standards is made by one of two general methods: [1] the welding processes and [2] the seamless processes.

4.1. Welding Processes

There are several means of producing welded tubular products from flat hot-rolled steel commonly known as skelp, plates, sheets, or strip.

4.1.1. *Furnace welding* is employed in the manufacture of butt-welded and lap-welded pipe and tubes. The principal steps in the butt-welding process are shown in Fig. 4.1. A continuous butt-weld mill in operation is shown in Fig. 4.2.

In the *butt-welding* process, skelp with square or slightly beveled edges is heated to a welding temperature. The skelp is then drawn from the furnace through a funnel-shaped welding die, or through the welding rolls by the continuous method; during either operation it is bent into tubular form, at which time the edges are brought together with sufficient pressure to weld. Butt-welded pipe and tubes are currently made in $\frac{1}{8}$–4-in. sizes.

In the *lap-welding* process, the skelp, with scarfed or beveled edges, is heated and bent to tubular form with edges overlapping. This form is then reheated to welding temperature, and passed over a mandrel located between two grooved welding rolls which compress and weld the overlapping edges. Lap-welded tubular products are currently made in sizes ranging from $1\frac{1}{4}$ in. nominal through 16 in. actual OD.

The term "lap welding" as it applies to furnace-welded pipe must not be confused with the same term when it is applied to electric-fusion-welded pipe (see Sec. 4.1.2). Furnace lap-welded pipe is of uniform wall thickness with no lap showing in the finished product, whereas electric-fusion lap-welded pipe retains the lap in the final product and shows a double wall thickness in some portion of the circumference of a ring cut from it. The AWWA steel pipe standards do not permit such lap joints in the shop welds of electric-fusion-welded pipe. Circumferential lap joints are permitted as field joints when made as specified.

4.1.2. *Electric welding* is done in several different ways. As ordinarily used, the term embraces both the electric-resistance and the arc or gas fusion method.

In *electric-resistance welding*, including flash welding, a series of operations is employed. First the flat rolled steel is cold shaped into

tubular form. Welding is then effected by the application of heat and pressure. The welding heat is generated by resistance to the flow of an electric current, which may be introduced through electrodes or by induction. Electric-resistance-welded tubular products are currently made in sizes from ⅛ in. nominal to 36-in. actual OD.

In *electric-arc or gas fusion welding*, the flat rolled steel, with edges suitably prepared, is formed into tubes by either hot or cold shaping. The plate, sheet, or strip may be shaped longitudinally (straight seam) or bent into helical form (spiral seam). The edges are welded with or without depositing at the same time filler metal in a molten or molten-and-vapor state. Mechanical pressure is not required to effect the welding. Fusion may be accomplished by either the electric-arc or the gas method, or by a combination of both. Fusion welding is employed in making pipe from about 4 in. in diameter to 30 ft or more in diameter. An initial forming operation in the manufacture of straight-seam electric-weld pipe is shown in Fig. 4.3.

4.2. Seamless Processes

Two general methods for producing seamless (weldless) tubular products in sizes currently up to 26 in. OD are: [1] hot piercing and [2] cupping and drawing. In the first method, ingots, blooms, billets, or rounds are hot pierced; then, by either hot rolling or hot drawing or a combination of both, the tubular product is processed to the desired size (Fig. 4.1).

In the second method, steel plates are hot cupped and hot drawn to the desired finished size. In order to produce seamless tubes or pipe in smaller sizes, or to closer dimensional accuracy than is practicable with the hot-worked product made by either of the above methods, pipe may be further processed by cold finishing.

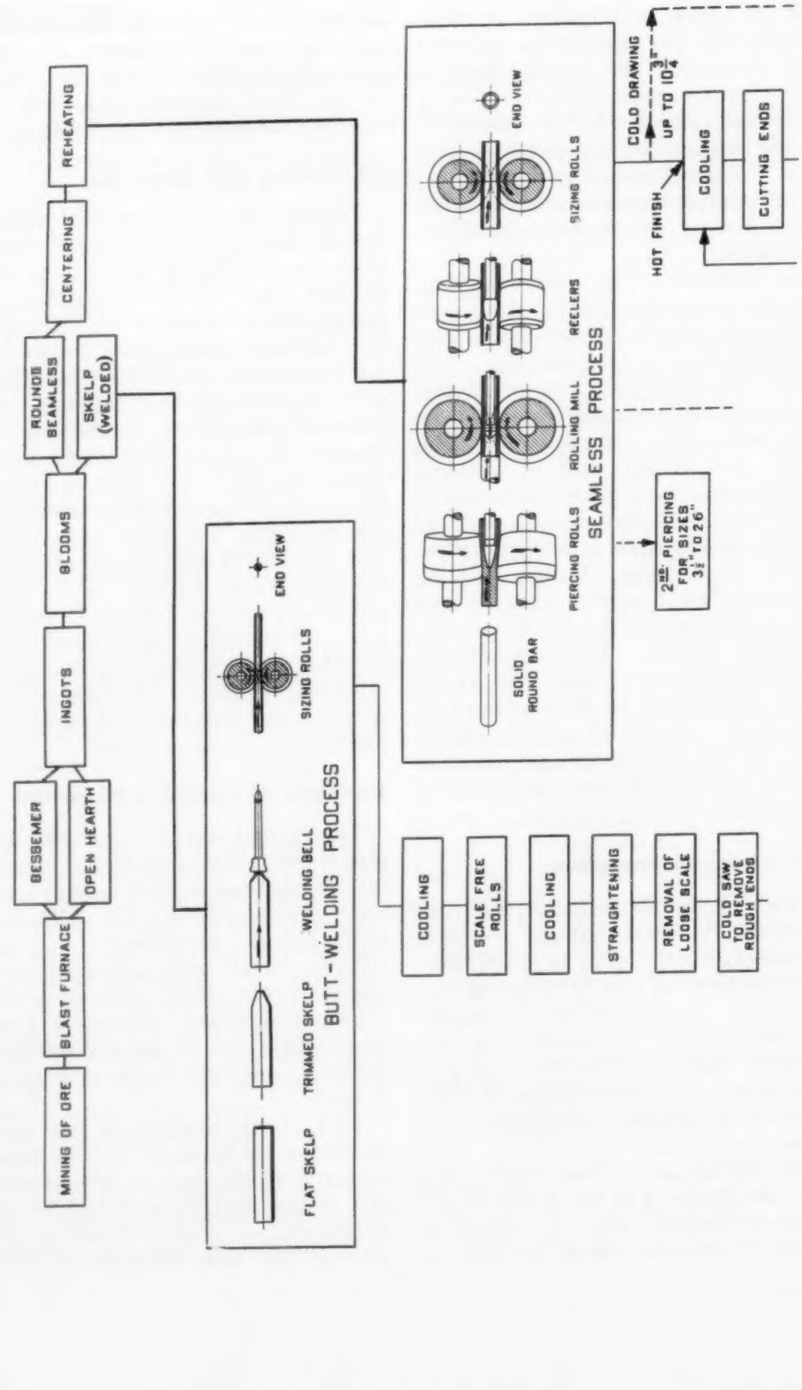
4.3. Testing and Inspecting

Testing and inspecting steel pipe is normal procedure during manufacture from the pouring of the heat to the finished pipe. When the purchaser's specifications stipulate that inspection and tests (except check analysis) for acceptance of the steel be made prior to shipment from the mill, the producer affords the purchaser's inspector all reasonable facilities to determine that the steel is being furnished in accordance with the specifications. Purchaser's inspection and sampling of steel tubular products are customarily carried out in conjunction with the producer's inspection and sampling operations. Any required separate inspection operation involving additional handling of steel is commonly negotiated between the purchaser and the producer.

4.4. Tests of Chemical Properties

The various services to which steel pipe is put require a variety of chemical compositions to produce the necessary characteristics. The chemical compositions established in the AWWA steel pipe standards are suited to the usual needs of water works applications. There are other steels which may be equally suitable, however, and they can be selected, if desired.

4.4.1. *Ladle analysis* is the term applied to the chemical analysis representative of the heat or blow of steel and is the analysis reported to the purchaser. It is determined by analyzing, for such elements as have


MINING OF ORE
BLAST FURNACE
BESSEMER
OPEN HEARTH
INGOTS
BLOOMS
ROUNDS SEAMLESS
SKELP (WELDED)
CENTERING
REHEATING
FLAT SKELP
TRIMMED SKELP
WELDING BELL
SIZING ROLLS
END VIEW
BUTT-WELDING PROCESS
COOLING
SCALE FREE ROLLS
COOLING
STRAIGHTENING
REMOVAL OF LOOSE SCALE
COLD SAW TO REMOVE ROUGH ENDS
SOLID ROUND BAR
PIERCING ROLLS
ROLLING MILL
REELERS
SIZING ROLLS
END VIEW
SEAMLESS PROCESS
2ND PIERCING FOR SIZES 3½" TO 26"
HOT FINISH
COLD DRAWING UP TO 10¾"
COOLING
CUTTING ENDS

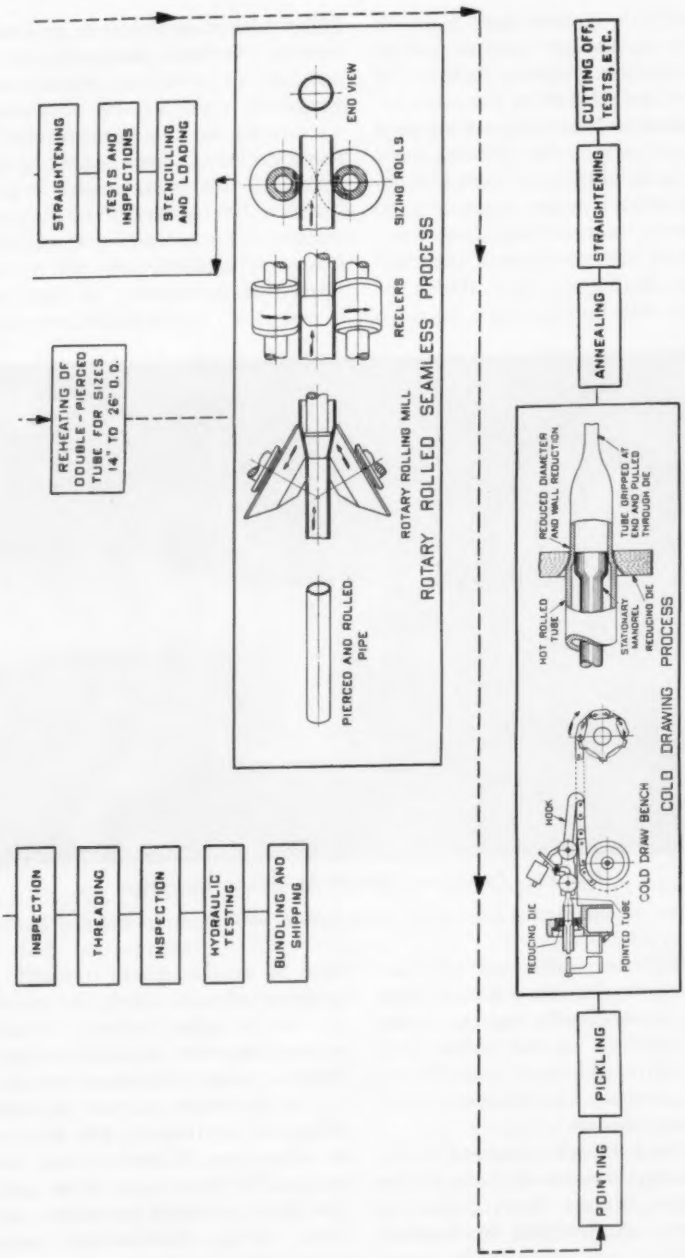


Fig. 4.1. Principal Steps in the Manufacture of Furnace Butt-Welded and Seamless Pipe

been specified, a test ingot sample obtained from the first part or middle part of the heat or blow during the pouring of the steel from the ladle.

It is common practice in most steel melting operations to obtain more than one ladle test ingot sample from each heat or blow; often three or more are taken—representing the first, middle, and last portions of the heat or blow. Drillings taken from the first or middle sample are used in determining the ladle analysis because experience has shown that these locations most closely represent the chemical analysis of the entire heat or blow. The additional samples are used for a survey of uniformity and for control purposes.

4.4.2. *Check analysis*, as used in the steel industry, means analysis of the metal after it has been rolled or forged into semifinished or finished forms. Such an analysis is made either to verify the average composition of the heat, to verify the composition of a lot as represented by the ladle analysis, or to determine variations in the composition of a heat or lot. Check analysis is not used, as the term might imply, to confirm the accuracy of a previous result. Check analysis of known heats is justified only where a high degree of uniformity of composition is essential; for example, on material that is to be heat treated. Such analysis should rarely be necessary for water pipe, except to identify or confirm the assumed analysis of plates or pipe which have lost identity.

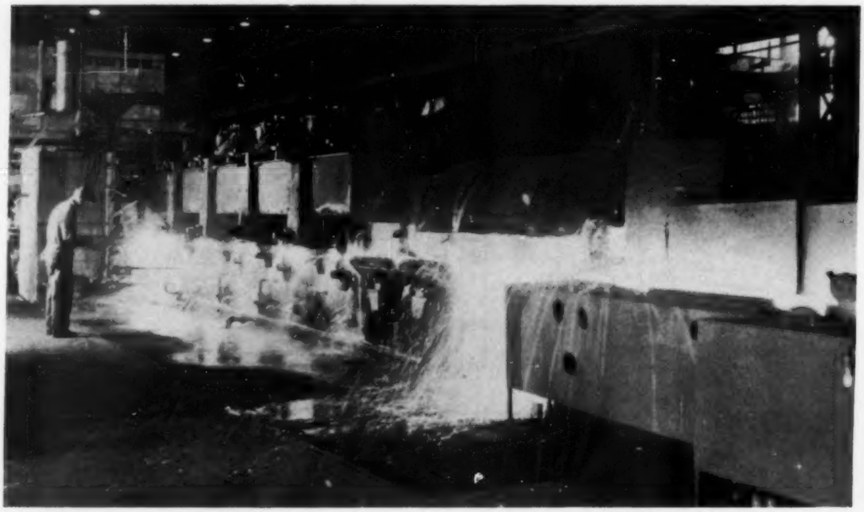


Fig. 4.2. Continuous Butt-Weld Mill in Operation

This continuous mill makes butt-welded pipe with a maximum diameter of about 4 in.

The results of analyses representing different locations in the same piece, or taken from different pieces of a lot, may differ from each other and from the ladle analysis owing to segregation. These permissible variations from the specified ranges or limits

have been established in the applicable specification or by common practice. The variations are a natural phenomenon which must be recognized by inspectors.

The methods of analysis commonly used are in accordance with the latest edition of *ASTM Methods for Chemical Analysis of Metals* (*1*) or those approved by the National Bureau of Standards, or others of equivalent accuracy.

4.5. Tests of Physical Properties

The *methods* of testing the physical properties of steel pipe are established in ASTM A370 (*2*). The *physical properties* required are contained in AWWA standards C201 and C202, or are as otherwise specified by the purchaser.

4.5.1. *Hydrostatic test of straight pipe.* Straight lengths of pressure pipe and tubing are customarily subjected to an internal hydrostatic pressure test. This operation is conducted as a part of the regular mill inspection procedure to help detect defects and is *not* intended to bear a direct relationship to bursting pressures, working pressures, or design data, although test pressures sometimes influence design pressures. AWWA Standards C201 and C202 contain tabulated test pressures for some sizes of pipe. Test pressures for other sizes must be calculated by methods established in the standards.

It is customary to make hydrostatic tests at the pressure required by the standard during the course of manufacture of the pipe. The requirements for hydrostatic testing in the presence of the purchaser's inspector involve additional handling, unless the inspector is present during the course of manufacture. The producer, upon request, customarily furnishes a certificate concerning such testing.

4.5.2. *Hydrostatic test of fittings and specials.* The AWWA standards establish conditions of manufacture for fittings and specials which, if met, eliminate the necessity of shop testing the fittings hydrostatically. Any deviation from this standard practice must be covered in the job specification. The AWWA standards also fix a suggested maximum test pressure for

Fig. 4.3. Initial Forming Operation

The operation is one step in the manufacture of straight-seam electric-weld pipe.

fittings and specials which are specified to be shop tested. This suggested maximum may be well below the test pressure for straight pipe lengths.

The shop hydrostatic testing of an individual, free, and unconnected fitting or special usually causes loads and stresses in the unit which it may not be required to resist when connected in the installation. Many authorities concur in the opinion that, under such circumstances, the use of

approved welding techniques by certified welding operators plus standard inspection is as good a guarantee of acceptable quality as is shop hydrostatic testing. In any case, the reserve strength inherent in most fittings should be investigated before ordering shop testing.

4.6. Tests of Dimensional Properties

The diameter, length, wall thickness, straightness, and out-of-roundness of pipe are checked as part of normal manufacturing procedure. Such dimensions are subject to the tolerances prescribed in the governing standards or specifications.

4.7. Good Practice

The manufacturing and testing procedures of reliable producers of steel pipe have been established through experience and practice. The controls on electric-welding processes covered in AWWA pipe standards, for instance, have been exactingly prepared and they are adequate. To elaborate, modify, or change any of the standard requirements may not be beneficial to the user and quite possibly may result in an inferior product rather than a better one. Unless great care has been taken in the preparation of a specification variation, it is best to use the standards as written, with regard to both manufacturing control and inspection. When different methods of pipe manufacture and test are found to be better than those in the standards, appropriate revisions are made in the latter, thus keeping them abreast of the best practice.

Acknowledgments

Figure 4.1 was supplied through the courtesy of National Tube Division, US Steel Corp., Pittsburgh, Pa.; Fig. 4.2, through the courtesy of Youngstown Sheet & Tube Co., Youngstown, Ohio; and Fig. 4.3, through the courtesy of Consolidated Western Steel Division, US Steel Corp., Los Angeles, Calif.

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CHAPTER 5

Hydraulics of Pipelines

THE data on flow of water in pipe herein given has special reference to transmission conduits. It is not intended to cover the flow of water through the complicated networks of distribution systems. Because this report is essentially a good-practice guide and not a textbook, the theoretical considerations are given only in sufficient detail to develop a general understanding of the subject.

5.1. General Considerations

The data on which present-day hydraulic-friction flow formulas are based have been accumulating over about two centuries. The older formulas, of which there are several, are all empirical. Although they do not all give the same answers for the same assumed conditions, and some engineers may consider them unreliable, they have been used to design many successful pipelines. Some large lines, however, have not performed as was expected.

The mechanism of resistance in the flow of fluids is complex and has not yet been fully evaluated. In the past each experimenter gathered his own data, added other data from previous experiments, and then attempted to fit a curve to the results. Therefore, it has not been possible for engineers generally to agree on one particular formula and then relate experiment and research to coefficients or factors used in that formula.

For unknown reasons, repeated flow determinations under apparently identical conditions have yielded results at variance with each other. It appears, however, that very few flow data have been studied statistically for the purpose of learning the standard deviation or error which may be inherent in making flow measurements. Only "limits of accuracy" have been reported, such as "± 5 per cent." The theory of probability, if applied to hydraulic-flow studies, as it has been to the results of other investigations, might provide the designer of the future a much needed factor of safety to use in his flow calculations.

In recent years general engineering practice in fields other than water works engineering has required the development of rationally founded formulas applicable to many fluids having different viscosity, density, and fluidity characteristics which change with temperature. It seems likely that such basically rational formulas will eventually be used by water works engineers also. This rational approach to flow calculation is making rapid progress, but consistent data on friction factors applicable to practical water works conditions are still scarce.

The proper formula to be used in a given instance remains a matter of engineering judgment. Several of the most commonly used formulas are discussed in this chapter to aid that judgment.

The formulas which were in general use in the water works field until about 1930 are termed here "conventional formulas." The formulas which have been developed for flow of other fluids, as well as water, and which are based on the fluid-mechanics concept are termed here "universal formulas" or "*f-R* equations." Much that follows is after Hinds (*1*).

5.2. Conventional Flow Formulas

In the conventional, or commonly used, equations there are three primary forms:*

Chezy: $$V = C_c\sqrt{rs} \quad (5.1)$$

Exponential: $$V = Cr^x s^y \quad (5.2)$$

Darcy: $$H = f\frac{L}{D}\cdot\frac{V^2}{2g} \quad (5.3)$$

A number of auxiliary equations have been proposed for the determination of the coefficient C_c in the Chezy formula. Among them are those of Kutter and Manning. When the Kutter equation or the Manning equation is substituted for C_c in the Chezy formula, the resulting formula is usually known as the "Kutter formula" or the "Manning formula," as the case may be.

The Kutter formula was developed almost exclusively from data on flow in open channels. Notwithstanding its origin and inapplicability to pipe running full, it has been used by some in the past to calculate flow in pipe. Few data on the Kutter formula are given in this report.

TABLE 5.1

Comparison of F_m *With Other Coefficients* *

Pipe Diam. *ft*	$F_m = 1.0$		$F_m = 1.5$		$F_m = 2.0$	
	C_{hw}	n	C_{hw}	n	C_{hw}	n
2	70	0.0180	109	0.0128	148	0.0101
4	72	0.0192	111	0.0133	152	0.0103
6	73	0.0198	114	0.0135	155	0.0104
8	74	0.0202	115	0.0137	157	0.0104
10	75	0.0204	117	0.0137	159	0.0103
12	76	0.0205	118	0.0137	160	0.0103

* Velocity assumed at 4 fps.

Based on Capen (2)

The most notable and widely used exponential formula in the water works field is that of Hazen and Williams. The Scobey exponential formula is popular in irrigation work. These two formulas are:

Hazen-Williams: $$V = 1.318C_{hw}r^{0.63}s^{0.54} \quad (5.4)$$

Scobey: $$H_s = K_s\frac{V^{1.9}}{D^{1.1}} \quad (5.5)$$

After an extensive study of existing large pipelines and past literature on the subject, Capen (*2*) concluded that "the great weight of evidence encountered indicates that the approximate Mills formula, in the form:

$$V = F_m D^{0.625} H_m^{0.5} \quad (5.6)$$

* All symbols used in this chapter are explained in the list of hydraulic symbols at the end of the chapter.

is the best to advocate for all around use for the design of modern large diameter pipes." A comparison of the friction coefficients in the Mills formula with those in the Hazen-Williams and Kutter formulas is given in Table 5.1.

5.3. Universal Flow Formulas

The most recent fluid-mechanics ideas are embodied in a set of equations designed to give values of the friction factor in the Darcy formula. These "*f-R* equations" were developed by Poiseuille, von Karman, Nikuradse, Prandtl, Colebrook, White, and Moody.

The *f-R* equations, being universal, must provide for viscosity. To maintain dimensionality, viscosity must be introduced through a dimensionless parameter. Such a parameter, well known and widely used for other purposes, is the Reynolds number.

The great contribution of Reynolds to hydraulic theory was his recognition of the part that viscosity plays in so many hydraulic problems. In simple language, what Reynolds attempted to do was to establish a relation by which experiments on small pipe (mainly as models) could be correlated to actual flow conditions of larger pipe or to flows with liquids of different viscosity. Fluid friction is due to viscosity, and in all problems having to do with flow in pipe or in channels, a necessary condition for similarity between model and actual structure is that the Reynolds number, R, shall be the same for both. The value of the Reynolds number is given by the formula:

$$R = \frac{VD}{\nu} \qquad (5.7)$$

Because the region where the Reynolds number varies from 1,000 to 5,000 is one of hydraulic instability,

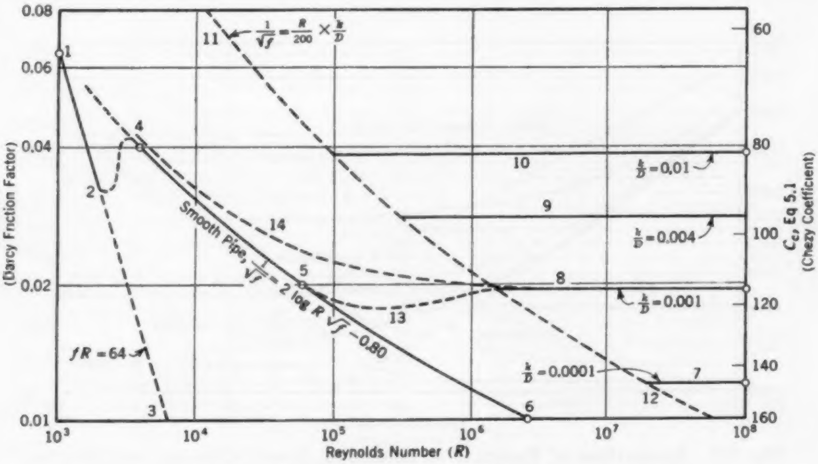


Fig. 5.1. Elements of *f-R* Equations

The curves show the relationships of the developed f—R *equations to each other and to the flow problem in general. (Figure from Ref. 1.)*

in which the flow changes from laminar to turbulent, it is essential that the Reynolds numbers of the model and the actual structure both stay on the same side of this region.

The relationships of the developed *f-R* equations to each other, and to the flow problem in general, are illustrated graphically in Fig. 5.1. Briefly, the flow is divided into three distinct stages separated by two transition zones. The first stage covers streamlined or laminar flow in smooth or rough pipe. For this stage, the friction is computed from an equation by Poiseuille, which plots as the single straight line, 1–2–3, in Fig. 5.1. The equation is not controversial, involves very low velocities, and never need be considered in the design of a water system.

At Point 2 in Fig. 5.1, the streamline formula breaks down and the flow becomes turbulent. The second stage, turbulent flow in smooth pipe, is represented by an equation of von Karman and Prandtl, which plots as a single curve, 4–5–6. The location of the point where Curve 1–2–3 ends and Curve 4–5–6 begins depends upon a number of variables and may be considered uncertain. The transition between these curves is represented by a curve such as 2–4, uncertain as to position and form. Because of the extremely low velocities involved, flow in the region of 2–4 is of no importance to the water works engineer unless he happens to be conducting flow tests which fall in this range.

Although the equation for Curve 4–5–6 applies primarily to smooth pipe, it also appears to apply to rough pipe through a limited velocity range. With an increase in Reynolds number, a break in the curve occurs in a transition zone, and eventually the curve resumes as some horizontal line, such as 7, 8, 9, or 10, depending on the relative roughness of the pipe. This roughness may be measured by the coefficient C_c in the Chezy formula, as shown in Fig. 5.1. It also may be designated as the ratio of the height (or some function of the height, spacing, and arrangement)

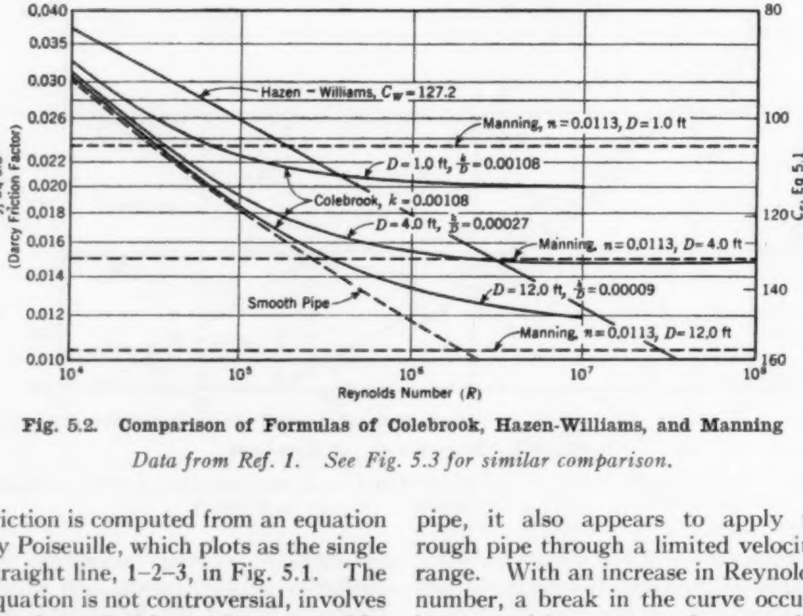


Fig. 5.2. Comparison of Formulas of Colebrook, Hazen-Williams, and Manning

Data from Ref. 1. See Fig. 5.3 for similar comparison.

of the roughness projections to the pipe diameter.

Curves 7, 8, 9, and 10 represent plots of another equation. They are independent of the Reynolds number. The nature of the transition between the smooth-pipe curve and the rough-pipe curves is uncertain.

The position of the Curve 11–12, which marks the limit of the zone of uncertainty and the beginning of the horizontal lines, is not exactly known. In fact, it probably is not a definite line. Its approximate location, however, has been given by Moody and others.

The equation for Curve 13 is unknown. If it were established that the break is always of this form, it would be on the side of safety to ignore it in practice. The horizontal lines could be extended to intersect the smooth-pipe curve, the latter being used to the left of the intersection.

Artificially roughened pipe was used in some experiments to study the changeover between turbulent flow in smooth pipe and complete turbulence in rough pipe. The changeover followed somewhat the form of Curve 14, the equation for which is not known. Colebrook and White, however, proposed a formula to bridge this gap. This formula covers, in fact, the whole range of turbulent flow. It is asymptotic to Curve 4–5–6 on the left and to the various horizontal lines (such as 8) on the right. The formula is:

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{1}{3.7}\cdot\frac{k}{D} + \frac{2.51}{R\sqrt{f}}\right) \quad (5.8)$$

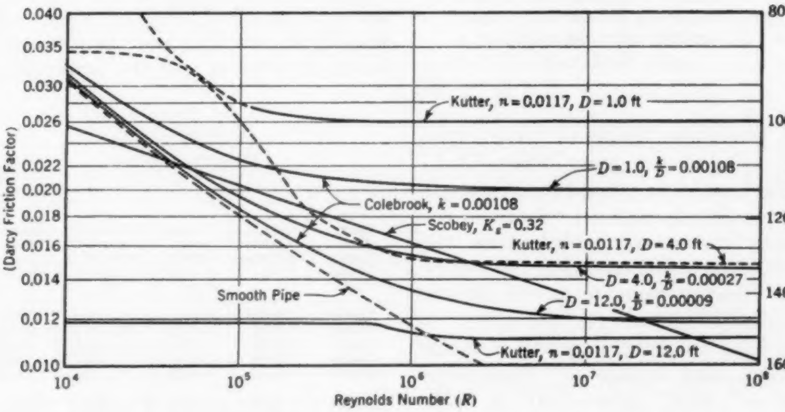


Fig. 5.3. Comparison of Formulas by Colebrook, Scobey, and Kutter

Data from Ref. 1. See Fig. 5.2 for similar comparison.

The Colebrook-White equation can hardly be classed as entirely empirical; neither can it be classed as rigidly theoretical. Its practical accuracy in the transition zone is well supported by tests.

The original Colebrook-White equation, however, was rather complex to use. Moody (*3*) later constructed a chart of rectangular coordinates based on the Prandtl–von Karman experiments, the Colebrook-White func-

TABLE 5.2

Theoretical Head Corresponding to Given Velocity

Velocity *fps*	Head *ft*	Velocity *fps*	Head *ft*
1	0.02	16	4.0
2	0.06	18	5.0
3	0.14	20	6.2
4	0.25	22	7.5
5	0.39	24	9.0
6	0.56	26	10.5
7	0.76	28	12.2
8	1.0	30	14.0
9	1.3	32	15.9
10	1.6	34	18.0
12	2.2	36	20.1
14	3.0	38	22.4

From Barnard (21)

tion, plus experiments on commercial pipe. Details are given in Sec. 5.4.2.

Much measured flow data on smooth interior pipe have been related to the Moody chart and published by the US Bureau of Reclamation (*4*). Pipe sizes ranged from 6 in. to 30 ft. Roughness factors (ϵ) are given in Sec. 5.4.2 for several kinds of inside coatings and linings in "continuous interior" steel pipe—that is, pipe with butt-welded or smooth field joints—and also for new, clean pipe of various materials with and without inside coatings and linings.

A graphical comparison of the formulas of Colebrook, Hazen-Williams, and Manning is shown in Fig. 5.2 for a wide range of conditions. A similar comparison of formulas by Colebrook, Scobey, and Kutter is shown in Fig. 5.3. The basic differences are apparent from the different slopes of the lines. If the universal equations become fully established as being applicable to water pipe, and roughness values are more definitely fixed for such pipe and linings, these equations should replace all others, especially for the design of supply lines. The presumption is that ultimately they will do so. The present use of conventional formulas for the design of *distribution* systems, however, appears practical and adequate.

5.4. Computations for Flow Through Pipe

The quantity of water which will pass through any given pipe is dependent upon the head or pressure producing flow, the diameter and length of the pipe, the condition of the pipe interior (whether smooth or rough), the number and abruptness of bends or elbows, and the presence of

TABLE 5.3

Slope Conversions

1 Fall per Foot of Pipe *ft*	2 Grade of Pipe %	3 Drop per 1,000 ft of Pipe *ft*	4 Drop per Mile of Pipe *ft*	5 Length of Pipe in 1-ft Drop *ft*
0.00005	0.005	0.05	0.264	20,000.0
0.0001	0.01	0.10	0.528	10,000.0
0.0002	0.02	0.20	1.056	5,000.0
0.0003	0.03	0.30	1.584	3,330.0
0 0004	0.04	0.40	2.112	2,500.0
0.0005	0.05	0.50	2.640	2,000.0
0.0006	0.06	0.60	3.168	1,666.7
0.0007	0.07	0.70	3.696	1,428.6
0.0008	0.08	0.80	4.224	1,250.0
0.0009	0.09	0.90	4.752	1,111.1
0.001	0.10	1.00	5.280	1,000.0
0.002	0.20	2.00	10.56	500.0
0.003	0.30	3.00	15.84	333.0
0.004	0.40	4.00	21.12	250.0
0.005	0.50	5.00	26.40	200.0
0.006	0.60	6.00	31.68	166.7
0.007	0.70	7.00	36.96	142.9
0.008	0.80	8.00	42.24	125.0
0.009	0.90	9.00	47.52	111.1
0.01	1.00	10.00	52.80	100.0
0.02	2.00	20.00	105.60	50.0
0.03	3.00	30.00	158.40	33.3
0.04	4.00	40.00	211.20	25.0
0.05	5.01	50.00	264.00	20.0
0.06	6.01	60.00	316.80	16.7
0.07	7.02	70.00	369.6	14.3
0.08	8.03	80.00	422.4	12.5
0.09	9.04	90.00	475.2	11.1
0.10	10.05	100.00	528.0	10.0
0.12	12.09	120.00	636.6	8.3

From Barnard (21)

tees, branches, valves, and other accessories in the line.

The total head or pressure affecting flow may be divided into four parts:

a. Velocity head loss, defined as the height through which a body must fall in a vacuum to acquire the velocity with which the water flows in the pipe. This loss is usually considered to be unrecoverable at the outlet. Numerical values are given in Table 5.2.

b. Entrance head loss, the head required to overcome the resistance at the entrance to the pipe is usually less than the velocity head. When the conditions are not specified, it is ordinarily taken as equal to one-half the velocity head, on the assumption of a sharp-edge entrance. Safe values for the ordinary entrance head loss may be obtained from Table 5.2 by taking half the velocity head corresponding to the velocity in the pipeline. Head losses for other than sharp-edge entrances may be found in treatises on hydraulics.

c. Loss of head through friction. Friction head loss may be determined by one of the formulas which have been discussed or by taking an average of results from the several formulas. (Data are given in this chapter to aid in solving both the

TABLE 5.4

Flow Equivalents

mgd	*gpm*	*cfs*	*mgd*	*gpm*	*cfs*
1	694	1.55	36	25.000	55.73
2	1,389	3.09	37	25,694	57.28
3	2,083	4.64	38	26,389	58.82
4	2,778	6.19	39	27,083	60.37
5	3,472	7.74	40	27,778	61.92
6	4,167	9.28	42	29,167	65.02
7	4.861	10.83	44	30,556	68.11
8	5,556	12.38	46	31,944	71.21
9	6,250	13.93	48	33,333	74.31
10	6,944	15.48	50	34,722	77.40
11	7,639	17.02	52	36,111	80.50
12	8,333	18.57	54	37,500	83.60
13	9,028	20.12	56	38,889	86.69
14	9,722	21.67	58	40,278	89.79
15	10,417	23.22	60	41,667	92.88
16	11,111	24.77	62	43,056	95.98
17	11,806	26.31	64	44,444	99.08
18	12,500	27.86	66	45,833	102.17
19	13,194	29.41	68	47,222	105.27
20	13,889	30.96	70	48,611	108.37
21	14,583	32.51	72	50,000	111.46
22	15,278	34.05	74	51,389	114.56
23	15,972	35.60	76	52,778	117.65
24	16,667	37.15	78	54,167	120.75
25	17,361	38.70	80	55,556	123.85
26	18,056	40.25	82	56,944	126.94
27	18,750	41.80	84	58,333	130.04
28	19,444	43.34	86	59,722	133.14
29	20,139	44.89	88	61,111	136.23
30	20,833	46.44	90	62,500	139.33
31	21,528	47.99	92	63,889	142.43
32	22,222	49.54	94	65,278	145.52
33	22,917	51.08	96	66,667	148.62
34	23,611	52.63	98	68,056	151.71
35	24,306	54.18	100	69,444	154.81

From Barnard (21)

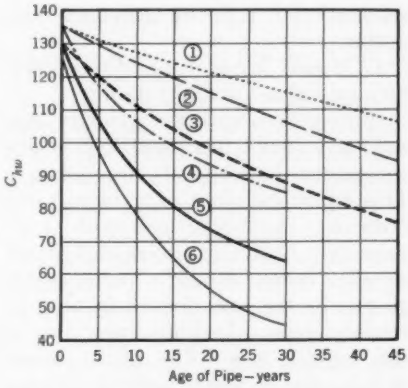


Fig. 5.4. Summary of Estimated and Actual Trends of Age-Coefficient Relationships for Tar-Coated Cast-Iron Pipe

The numbers on the curves represent: [1] estimated trend "inactive waters"; [2] estimated trend "conservative for eastern waters"; [3] estimated Williams-Hazen trend "average conditions," 20-in. pipe; [4] composite of actual trend curves in nine cities—supply lines average 28 in. in diameter; [5] composite of actual trend curves in nine cities—supply and distribution mains average 20.5 in. in diameter; and [6] composite of actual trend curves in ten cities—distribution mains average 6.85 in. in diameter. (*Data from Ref. 5.*)

conventional and the universal formulas.)

d. Minor losses, due to elbows, fittings, valves, and the like.

In long lines with low velocity, the sum of velocity head and loss at entrance may be relatively insignificant. This figure becomes very important, however, in short lines with high velocity. Ordinary tables and charts showing flow of water in pipe usually give only the loss due to friction in straight pipe. In long lines, this is the biggest loss. The minor losses of head due to bends and the like are occasionally ignored in long lines. In any given line, however, it is best to consider all losses, so that none of importance is overlooked. The minor losses always should be recognized when evaluating flow tests.

In the final correct solution to a flow problem (which is usually found by the trial-and-error method), the sum of all losses must equal the available head or pressure producing flow. The foregoing formulas determine H or V, and the volume of flow, Q, is found from:

$$Q = AV \qquad (5.9)$$

The information contained in Tables 5.3–5.7 will be found generally useful when making hydraulic calculations.

5.4.1. *Computations using conventional formulas.* The Hazen-Williams formula is widely used by hydraulic engineers. As coefficients covering various types of materials and linings have been developed and related to this formula, it is exceptionally useful for comparison as well as design purposes. Table 5.8 gives coefficients for the Hazen-Williams formula based upon hydraulic tests on pipelines of various materials and ages, both with tar-dipped lining and with lining of cement or coal-tar enamel (*5*). Figure 5.4, from the same source (*5*), shows the effect of age of pipe. A graph for solving the Hazen-Williams formula for $C = 130$ is given in Fig. 5.5 for sizes 4–144 in. Solutions for $C = 150$ are given in Fig. 5.6 for sizes 6–36 in. The multiplying factors in Table 5.9 provide a convenient means of changing the flow capacity shown in Fig. 5.5 and 5.6 to the flow for values of C other than 130 or 150.

Graphs for the solution of the Manning formula using $n = 0.011$ and

TABLE 5.5

Pressure (psi) for Heads (ft)

Head *ft*	Additional Units									
	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
	Pressure—*psi*									
0	—	0.43	0.87	1.30	1.73	2.16	2.60	3.03	3.46	3.90
10	4.33	4.76	5.20	5.63	6.06	6.49	6.93	7.36	7.79	8.23
20	8.66	9.09	9.53	9.96	10.39	10.82	11.26	11.69	12.12	12.56
30	12.99	13.42	13.86	14.29	14.72	15.15	15.59	16.02	16.45	16.89
40	17.32	17.75	18.19	18.62	19.05	19.48	19.92	20.35	20.78	21.22
50	21.65	22.08	22.52	22.95	23.38	23.81	24.25	24.68	25.11	25.55
60	25.98	26.41	26.85	27.28	27.71	28.14	28.58	29.01	29.44	29.88
70	30.31	30.74	31.18	31.61	32.04	32.47	32.91	33.34	33.77	34.21
80	34.64	35.07	35.51	35.94	36.37	36.80	37.24	37.67	38.10	38.54
90	38.97	39.40	39.84	40.27	40.70	41.13	41.57	42.00	42.43	42.87

From Barnard (21)

the Scobey formula using $K_s = 0.36$ are given in Fig. 5.7 and 5.8, respectively. Comparison values of F_m for use in the Mills formula are given in Table 5.1 for a velocity of 4 fps, and a graph for $F_m = 1.75$ is given in Fig. 5.9. Multiplying factors for other coefficients in the Manning, Scobey, and Mills formulas are given in the explanatory text beneath the graphs.

5.4.2. *Computations using universal formulas.* To assist in solutions of the Darcy formula and the related *f-R* equations, several aids are given. The *f-R* equations are logarithmic and their form is forbidding, but they are readily solved by the Moody type of diagram. The solution process is most easily understood by referring to explanatory Fig. 5.10. (Figure 5.10 is not drawn to a working scale. For actual solutions, use Fig. 5.11.) A known value of k (ϵ in Fig. 5.11) is divided by a trial (or known) value of D to get a value of $\frac{k}{D}$, say as at Point A (Fig. 5.10). Knowing (or assuming for trial) values of V and ν for the same value of D, a value of R is computed as at Point B. Then, by tracing along the $\frac{k}{D}$ line to Point C, above B, the value of f at Point D may be read. For a mean temperature and a specified fluid, an auxiliary scale for Vd may be used in place of R as shown at the top of Fig. 5.10. In the working diagram, Fig. 5.11, this has been done for water and atmospheric air, both at 60°F. (Note: In the auxiliary scales in Fig. 10 and 11, $d = 12D$ has been used.)

5.4.2.1. *Viscosity, temperature, and* R. Table 5.10 gives the kinematic viscosity of water corresponding to given temperatures. This is preliminary to determining the Reynolds number. From a practical standpoint, it is reasonable to assume a water temperature of 60°F in design, and this is used in design diagram Fig. 5.11. When flow tests are being made, however, it should be recognized that a change in temperature has an effect even with water. Hinds (*1*) calculated the effect of temperature changes of ±20°F in a low range of R (average 10^4) and in a high range (average 10^7). The relative percent-

TABLE 5.6

Head (ft) for Pressures (psi)

Pressure *psi*	Additional Units									
	0	+1	+2	+3	+4	+5	+6	+7	+8	+9
	Head—*ft*									
0	—	2.3	4.6	6.9	9.2	11.5	13.9	16.2	18.5	20.8
10	23.1	25.4	27.7	30.0	32.3	34.6	36.9	39.3	41.6	43.9
20	46.2	48.5	50.8	53.1	55.4	57.7	60.0	62.4	64.7	67.0
30	69.3	71.6	73.9	76.2	78.5	80.8	83.1	85.4	87.8	90.1
40	92.4	94.7	97.0	99.3	101.6	103.9	106.2	108.5	110.8	113.2
50	115.5	117.8	120.1	122.4	124.7	127.0	129.3	131.6	133.9	136.3
60	138.6	140.9	143.2	145.5	147.8	150.1	152.4	154.7	157.0	159.3
70	161.7	164.0	166.3	168.6	170.9	173.2	175.5	177.8	180.1	182.4
80	184.8	187.1	189.4	191.7	194.0	196.3	198.6	200.9	203.2	205.5
90	207.9	210.2	212.5	214.8	217.1	219.4	221.7	224.0	226.3	228.6

From Barnard (21)

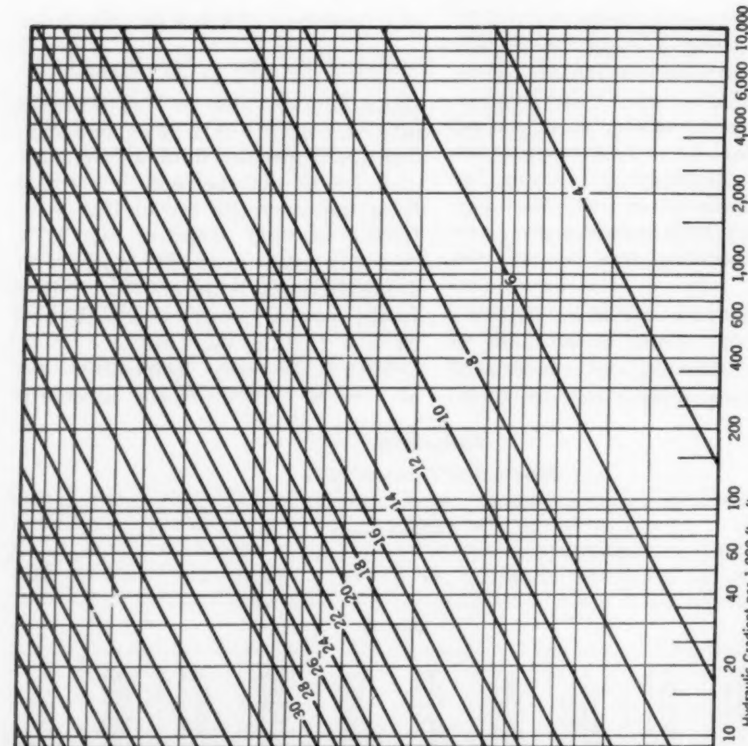


Fig. 5.5. Solution of Hazen-Williams Flow Formula for $C = 130$

For multiplying factors, see Table 5.9. (Figure from Ref. 20.)

ages are shown in Tables 5.11 and 5.12. The data are plotted in Fig. 5.10, where points *a*, *b*, and *c* represent figures in Table 5.11. Points *a'*, *b'*, and *c'* represent data in Table 5.12. The effect is greater in pipe with lower values of *R* and decreases as *R* increases. For turbulent flow in rough pipe, say above Line *I*, there would be little or no effect for this 40°F range of temperature.

5.4.2.2. *Roughness factor* ϵ. Figures 5.12 and 5.13 are diagrams of roughness factors for steel and other pipe needed for the solution of the Moody formula.

5.4.2.3. *Darcy friction factor*. Figure 5.11, previously discussed, is a Moody design diagram by which to determine *f* in the Darcy formula in accordance with Sec. 5.4.2.

5.5. Flow Through Fittings

5.5.1. *Equivalent-length method*. Experiments have shown that the head loss in bends, fittings, and valves is related to flow velocity and pipe diameter in a manner somewhat similar to that in straight pipe. Consequently, it is possible to determine the length of a theoretical piece of straight

TABLE 5.7

Pressure Equivalents

Mercury *in.*	Water *in.*	*psi*	Mercury *in.*	Water *in.*	*psi*
1	13.6	0.49	13	176.8	6.38
2	27.2	0.98	14	190.4	6.87
3	40.8	1.47	15	204.0	7.36
4	54.4	1.96	16	217.6	7.85
5	68.0	2.45	17	231.2	8.34
6	81.6	2.94	18	244.8	8.83
7	95.2	3.44	20	272.0	9.82
8	108.8	3.93	22	299.2	10.80
9	122.4	4.42	24	326.4	11.78
10	136.0	4.91	26	353.6	12.76
11	149.6	5.40	28	380.8	13.74
12	163.2	5.89	30	408.0	14.72

From Barnard (21)

TABLE 5.8

Hazen-Williams Coefficients for Pipe With Various Interior Surfaces

Type of Pipe or Interior Surface	Avg *C*
New tar-dipped cast iron	
16-in. and larger (supply and transmission mains)	135*
Smaller than 16-in. (distribution mains)†	125*
Cement lining (hand applied)	136‡
Cement lining (centrifugally applied)	150‡
Coal-tar enamel (centrifugally applied)	
16-in. and larger (supply and transmission mains)	150*
Smaller than 16-in. (distribution mains)†	145*

* Based on nominal diameter.
† Allowance included for tees, valves, bends, corporation cocks and so on.
‡ Based on net diameter.

pipe in which the loss of head due to friction would be the same as for some fitting. This method of "equivalent lengths" is recognized by several authorities (*6, 7*).

When using this plan, determine the actual centerline length of the pipeline by adding to the length of straight pipe in the line the center-to-face dimensions (in line of flow) of all the fittings. Next, using data from Table 5.13, total the "equivalent length in pipe diameters" for all the fittings. These "equivalents" account for the *additional* friction due to turbulence in the fittings. Thus, the fittings are assumed to have "no length." Convert this number of pipe diameters to the equivalent-length distance by multiplying the number by the pipe diameter in feet. Add this distance to the actual centerline length of the pipeline through all the fittings. The total friction loss in this theoretically lengthened straight pipeline, calculated using the applicable unit loss per foot, is assumed to equal that in the actual (shorter) pipeline containing the fittings.

Table 5.13 shows length equivalents which are reasonably correct. The actual length of the pipeline containing the fittings should be increased by the equivalent lengths indicated in Table 5.13 before determining the slope of the hydraulic gradient.

After studying the results of experiments on losses in bends and fittings on a *rational* basis involving surface roughness and Reynolds numbers, Pigott (*8*) concluded "that the equivalent pipe length is by all means the most reliable and convenient method of tabulating losses in different kinds of fittings and bends." He states, however, that losses through valves "can be treated as largely

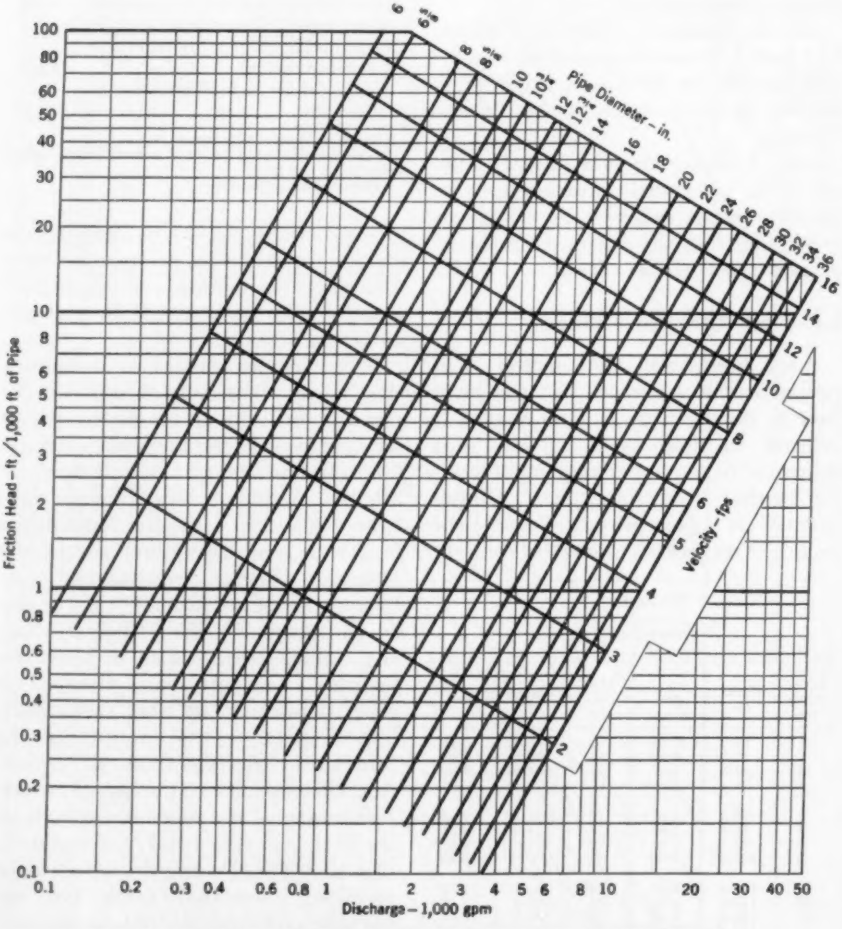


Fig. 5.6. Solution of Hazen-Williams Flow Formula for $C = 150$

For multiplying factors, see Table 5.9. (Figure from Ref. 21.)

varying with velocity head only." Such loss figures may originate with the manufacturer of the valves.

5.5.2 *Rational method.* Means of calculating losses through miter bends, using a resistance coefficient K applying to the velocity head $\frac{V^2}{2g}$, have been published (*9*). The resistance coefficients for smooth and rough pipe taken from this source are given in Fig. 5.14 for $R = 225{,}000$.

According to one authority (*4*), no information of value has been found on bend losses in large pipelines, principally because long reaches of straight pipe must accompany a bend if reliable measurements are to be made. The same authority states that there is some good indication, however, that the bend loss in large pipe may be overestimated by 50–100 per cent when using the generally accepted coefficients of 0.15 $\frac{V^2}{2g}$ for a 90-deg bend and 0.11 $\frac{V^2}{2g}$ for a 45-deg bend.

5.5.3. *Ordinary field curvature.* Usually it is not necessary to make allowance for minor losses (except entrance) in ordinary pipelines con-

TABLE 5.9

Multiplying Factors Corresponding to Various Values of C *in Hazen-Williams Formula**

Values of C	160	155	150	145	140	130	120	110	100	90	80	60	40
Base C = 150 (Use with Fig. 5.6)													
Relative discharge and velocity for given loss of head	1.067	1.033	1.000	0.967	0.933	0.867	0.800	0.733	0.667	0.600	0.533	0.400	0.267
Relative loss of head for given discharge	0.887	0.941	1.000	1.065	1.136	1.297	1.511	1.775	2.117	2.573	3.199	5.447	11.533
Base C = 130 (Use with Fig. 5.5)													
Relative discharge and velocity for given loss of head	1.231	1.192	1.154	1.115	1.077	1.000	0.923	0.846	0.769	0.692	0.615	0.462	0.308
Relative loss of head for given discharge	0.681	0.722	0.768	0.817	0.872	1.000	1.160	1.362	1.625	1.972	2.455	4.180	8.850
Base C = 100													
Relative discharge and velocity for given loss of head	1.600	1.550	1.500	1.450	1.400	1.300	1.200	1.100	1.000	0.900	0.800	0.600	0.400
Relative loss of head for given discharge	0.419	0.445	0.472	0.503	0.537	0.615	0.714	0.838	1.000	1.215	1.511	2.574	5.447

* Multiplying factors are shown for determining velocity, discharge and loss of head corresponding to other values of the coefficient C when tables or charts are available giving figures based on $C = 150$, $C = 130$ or $C = 100$. Comparison of discharge and friction losses in old and new pipe as well as in pipe of different materials is also easily made from any table or chart based on one of the three values of C just mentioned. For instance, if a new pipe of a given material has a coefficient of 150—and the discharge is found from a table or chart based on $C = 150$—then another pipe for which $C = 130$ will carry 0.867 times as much water with the same friction loss or, if carrying the same amount of water, will show a friction loss 1.297 times that of the first pipe.

From Barnard (21)

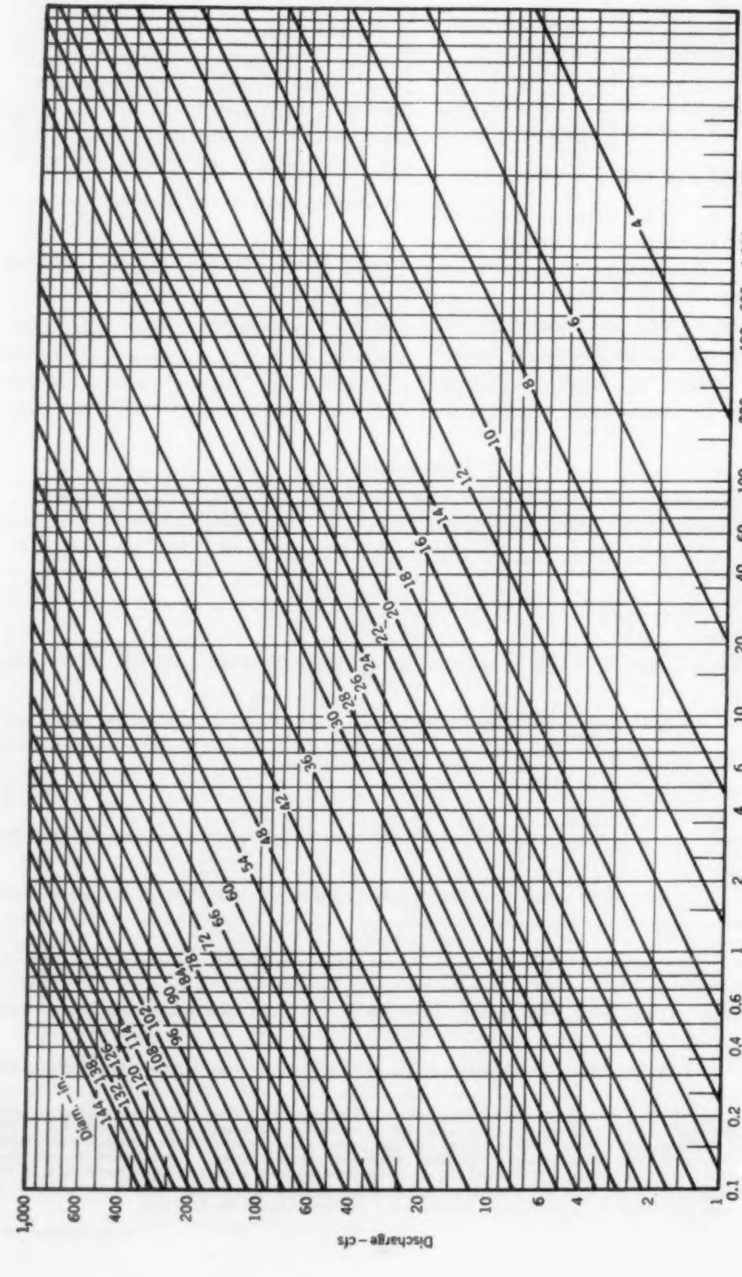


Fig. 5.7. Solution of Manning Flow Formula for $n = 0.011$ (See Data on Facing Page)

taining no fittings. Such losses as occur at the slight deflections permissible in the standard field joints are accounted for by the conventional flow formulas themselves.

5.6. Economical Diameter of Pipe

Determining the diameter of a pipe by means of hydraulic-flow formulas exclusively may not result in the best size to use. This is especially true where pumping is necessary or the penstock of an electric power plant is being designed. It may even be true for a supply line where the quantity is great, the available gravity head creating flow is small, and the resulting velocity is so low that very large pipe is required. In the latter case, supplementary pumping may result in a more economical installation.

TABLE 5.10

Kinematic Viscosity of Water for Normal Temperatures at Atmospheric Pressure

Temperature °F	Kinematic Viscosity sq ft/sec
32	1.93×10^{-5}
40	1.67×10^{-5}
50	1.41×10^{-5}
60	1.21×10^{-5}
70	1.05×10^{-5}
80	0.930×10^{-5}
90	0.823×10^{-5}
100	0.736×10^{-5}
120	0.610×10^{-5}
150	0.476×10^{-5}
180	0.385×10^{-5}
212	0.319×10^{-5}

TABLE 5.11

Effect of Temperature Change Upon Friction Factor f for Low Values of Reynolds Number

Temperature °F	Reynolds Number, R	Friction Factor, f	Relative Percentage of f
40	7,300	0.0336	109
60	10,000	0.0309	100
80	13,200	0.0287	93

The diameter of the pipe used should be that which results in the lowest capitalized cost. The capitalized cost is based on costs of initial material and equipment, installation, operation, pumping, maintenance, interest on investment, and replacement. On extensive projects it is customary to design a number of alternatives and from them select the most economical and practical one.

5.6.1. *Aqueducts*. Economic studies of large aqueducts are frequently complicated by the desirability of combining different means of carrying water—for instance, through open conduits, pipe, and tunnels—in the same system. Hinds (*10, 11*) demonstrated the use of graphical means in making such studies in the design of the Colorado River Aqueduct. The method of finding "economical slopes" elaborated by Hinds had been used previously in the design of the Owens River Aqueduct of Los Angeles (*12*) and the Catskill Aqueduct of New York (*13*).

Data for Use With Fig. 5.7

(*Figure From Ref. 20.*)

Multiplying Factors for Friction Coefficient Values—Base $n = 0.011$

Other n values	0.009	0.010	0.011	0.012	0.013
Relative discharge	1.222	1.100	1.000	0.917	0.846

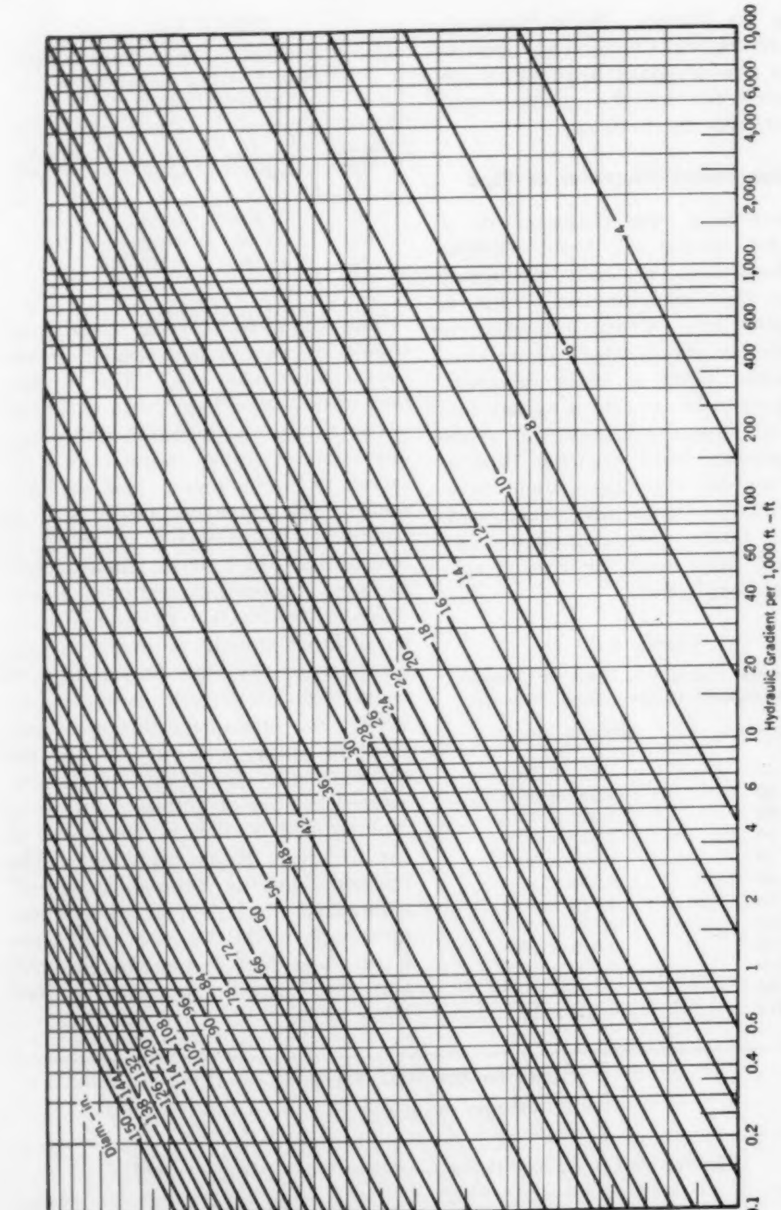


Fig. 5.8. Solution of Scobey Flow Formula for $K = 0.36$ (See Data on Facing Page)

5.6.2. *Penstocks.* For penstocks where the cost of steel may be expressed as a function of its weight, the following formula (*14, 15*) has been found convenient for quick approximation of the best pipe size as a basis for further detailed study:

$$D = 0.215 \sqrt[7]{\frac{fbQ_a^3S}{aiH_a}} \quad \ldots\ldots (5.10)$$

in which D and f are as previously noted and:

b = value of power (\$/hp/yr)
Q_a = average discharge (cfs)
S = allowable unit stress in steel (psi)
a = cost of steel (\$/lb)
i = yearly fixed charges on pipeline, expressed as a ratio
H_a = average head on penstock including water hammer (ft).

An old rule (*15*) for penstocks that approximates Eq 5.10 stated that: "pipe fulfills the requirements of greatest economy wherein the value of the energy annually lost in frictional resistance equals 0.4 of the annual cost of the pipeline."

For penstocks under low head such that a practical minimum pipe thickness, t, must be used, the formula (*15*) is:

$$D = 0.219 \sqrt[6]{\frac{fbQ^3}{tai}} \quad \ldots\ldots\ldots (5.11)$$

As these formulas relate the annual cost of the pipe and the annual cost of power lost in overcoming friction, they may aid in determining the economical diameter of a pumping line prior to further detailed study.

5.6.3. *Distribution systems.* Methods of determining economical sizes of pipe for distribution systems have been published (*16*).

TABLE 5.12

Effect of Temperature Change Upon Friction Factor f for High Values of Reynolds Number

Temperature °F	Reynolds Number, R	Friction Factor, f	Relative Percentage of f
40	7,300,000	0.00849	105
60	10,000,000	0.00810	100
80	13,200,000	0.00779	96

5.7. Standard Sizes

The final calculation for diameter and flow generally should be based on using a size or sizes listed in Tables 3.1 and 3.2 in Chap. 3, Table 6.2 in Chap. 6, and Table 2 in AWWA Standard C201.

5.8. Inlets and Transitions

The water to be carried must enter the pipeline properly if hydraulic calculations are to be accurate. The

Data for Use With Fig. 5.8

(*Figure From Ref. 20.*)

Multiplying Factors for Friction Coefficient Values—Base K_s = 0.36

Other K_s values	0.32	0.34	0.36	0.38	0.40
Relative discharge	1.125	1.059	1.000	0.946	0.900

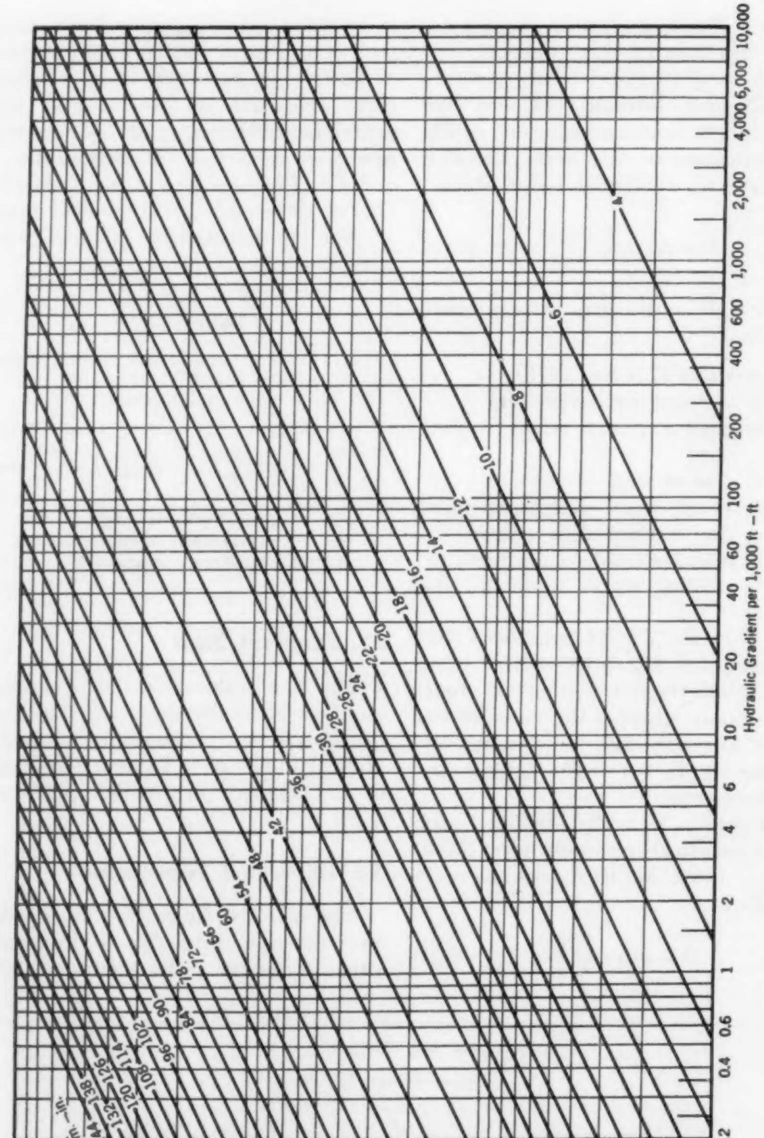


Fig. 5.9. Solution of Mills Flow Formula for $F = 1.75$ (See Data on Facing Page)

TABLE 5.13

Length of Straight Pipe in Which Friction Head Loss Is Equivalent to Turbulence Loss in Given Fittings Having "No Length"

Type of Fitting	Approximate Length Equivalent in Pipe Diameters
Miter elbows	
22½° 2 piece	4
30° 2 piece	7
45° 2 piece	15
45° 3 piece	10
60° 2 piece	25
60° 3 piece	15
90° 2 piece	65
90° 3 piece	25
90° 4 piece	15
Tee	
Flow through run	20
Flow side outlet to run; or run to side outlet	
No throat	65
With throat	45
Lateral	45
Sudden contraction	
Ratio of inlet diam. to outlet diam.:	
4 to 1	14*
2 to 1	11*
4 to 3	7*
Sudden enlargement	
Ratio of inlet diam. to outlet diam.:	
1 to 4	32*
1 to 2	20*
3 to 4	7*

Type of Fitting	Approximate Length Equivalent in Pipe Diameters
Reducer	
¼ reduction	26*
½ reduction	32*
Pipe entrance in concrete wall	
Ordinary square corner	16
Converging cone (apex angle 5–10°)	6
Pipe bends (smooth 90°, not mitered)	
Ratio of radius of bend to diam. of pipe:	
1	18
2	9
3	8
4	7
5	8
6	9
8	12
10	14
12	16
14	17
16	18
18	18
20	18
Gate Valve	
Fully open	7
¼ closed	40
½ closed	200
¾ closed	850
Swing Check Valve	
Fully open	80

* Figures apply to the smaller diameter.

From Barnard (21)

Data for Use With Fig. 5.9

(*Figure From Ref. 20.*)

Multiplying Factors for Friction Coefficient Values—Base $F_m = 1.75$

Other F_m values	2.00	1.85	1.75	1.65	1.50
Relative discharge	1.143	1.057	1.000	0.943	0.857

more important the pipeline, the more attention must be given this subject. Hydraulic-design data and general engineering information are available (*13, 17, 18*).

5.9. Air Entrainment and Release

Air entrained in flowing water tends to form bubbles at or near the summits in a pipeline. If not removed, such bubbles become serious obstacles to flow. The formation of a hydraulic jump in a pipe at the end of these bubbles is an important factor in removing the air. The ability of the hydraulic jump to entrain the air and have it carried away by the flowing water has been investigated. Quantitative data have been published (*19*) relating the characteristics of the jump to the rate of air removal. Removal of air through air valves is discussed in Chap. 11.

5.10. Good Practice

The water works engineer will use the hydraulic-friction formulas with which he is most familiar and with which he has had experience. Several of the common conventional formulas have been discussed in this chapter. In a particular case, the results calculated using the different conventional formulas can be compared. The water works engineer should, however, recognize the increasing use of the rational or "universal" formulas given here, become familiar with them, and make check calculations using them. He should be conservative in

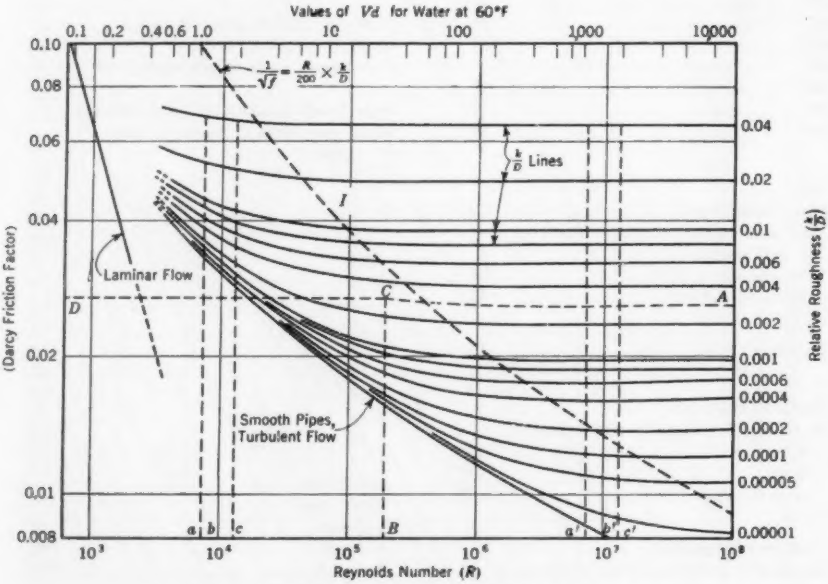


Fig. 5.10. Method of Solution of Colebrook Formula

The figure is not drawn to working scale. For actual solutions, use Fig. 5.11. (Figure from Ref. 1.)

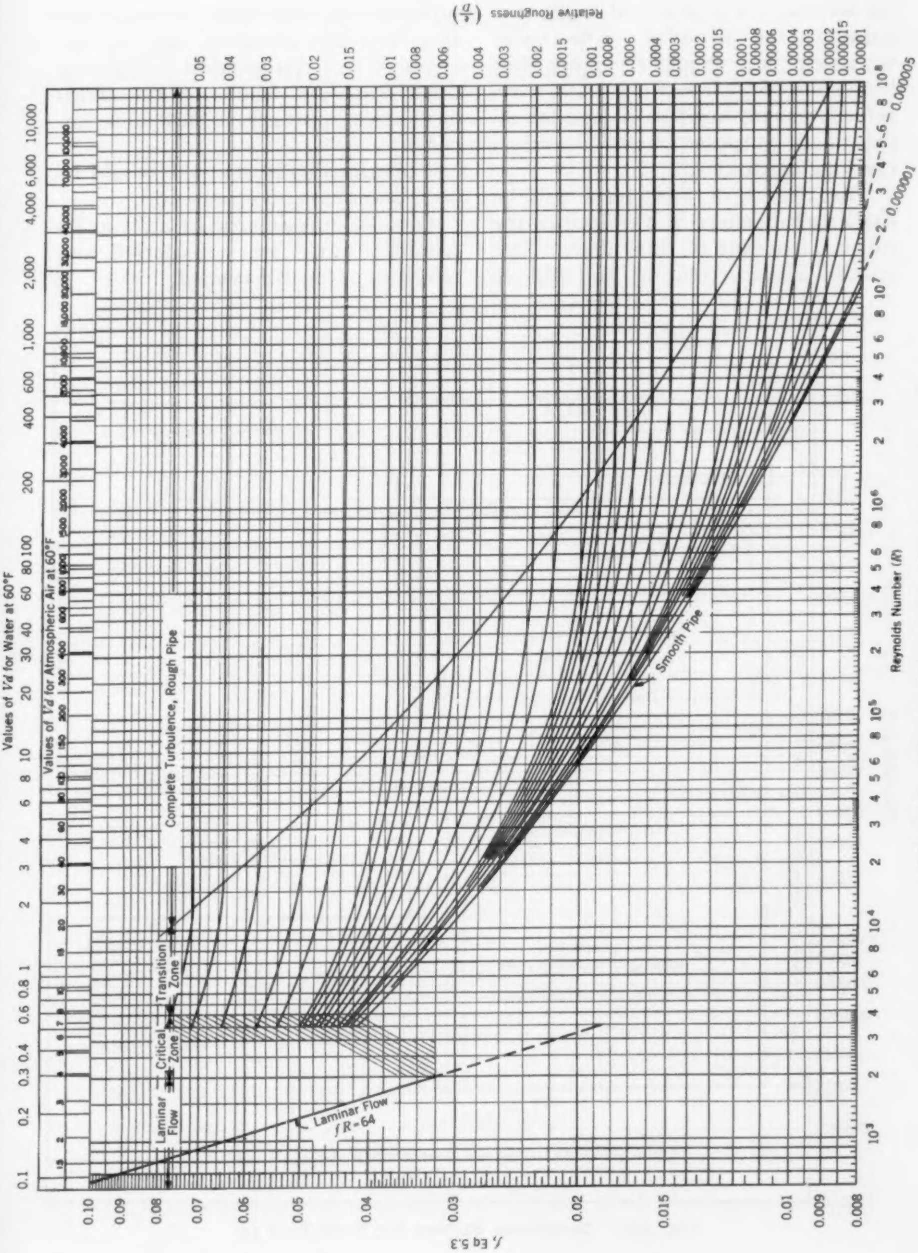


Fig. 5.11. Moody Diagram for Friction in Pipe (9)

his selection of a practical coefficient value in the formulas. The water works engineer should recognize that both spun coal-tar-enameled and spun cement-mortar-lined steel pipe for all practical purposes have identical carrying capacities.

The results of flow tests will be more useful generally if related to the rational concept of fluid flow. This entails more attention to relative surface roughness, water temperature, and Reynolds numbers, and an analysis of test results aimed at fitting them into the frame of the fluid-mechanics approach to flow determination.

The sizes finally selected should be both practical and economical.

Possible entrainment of air and its removal must be considered and remedies applied if needed.

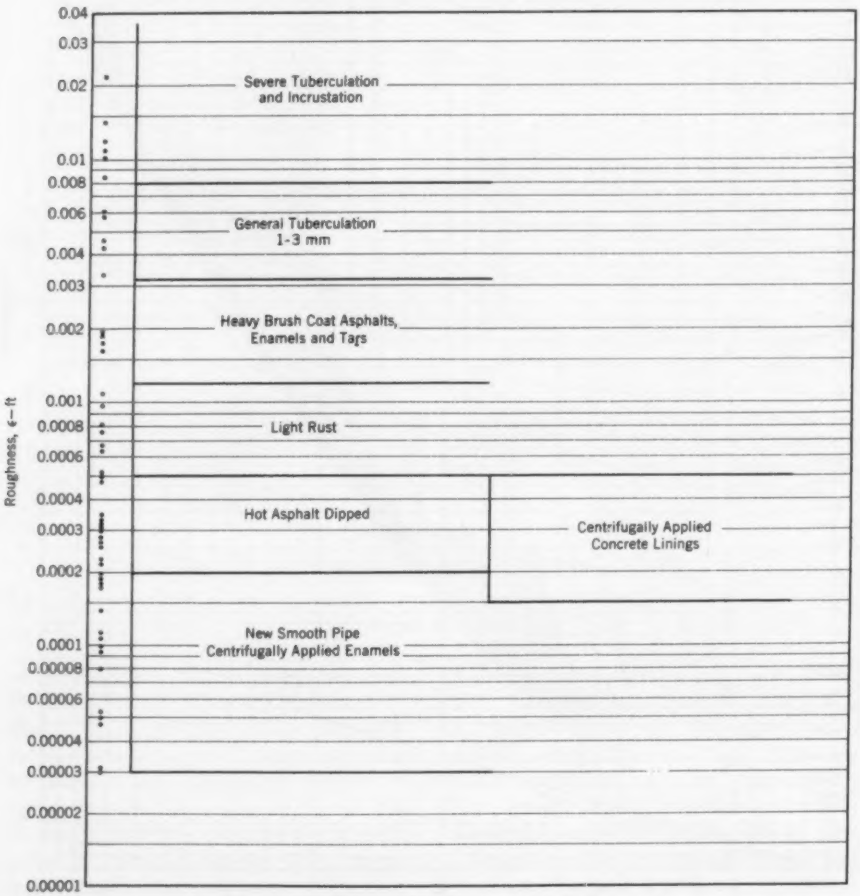


Fig. 5.12. Roughness Factors for Steel Pipe (*4*)

The roughness factors are needed for the solution of the Moody formula.

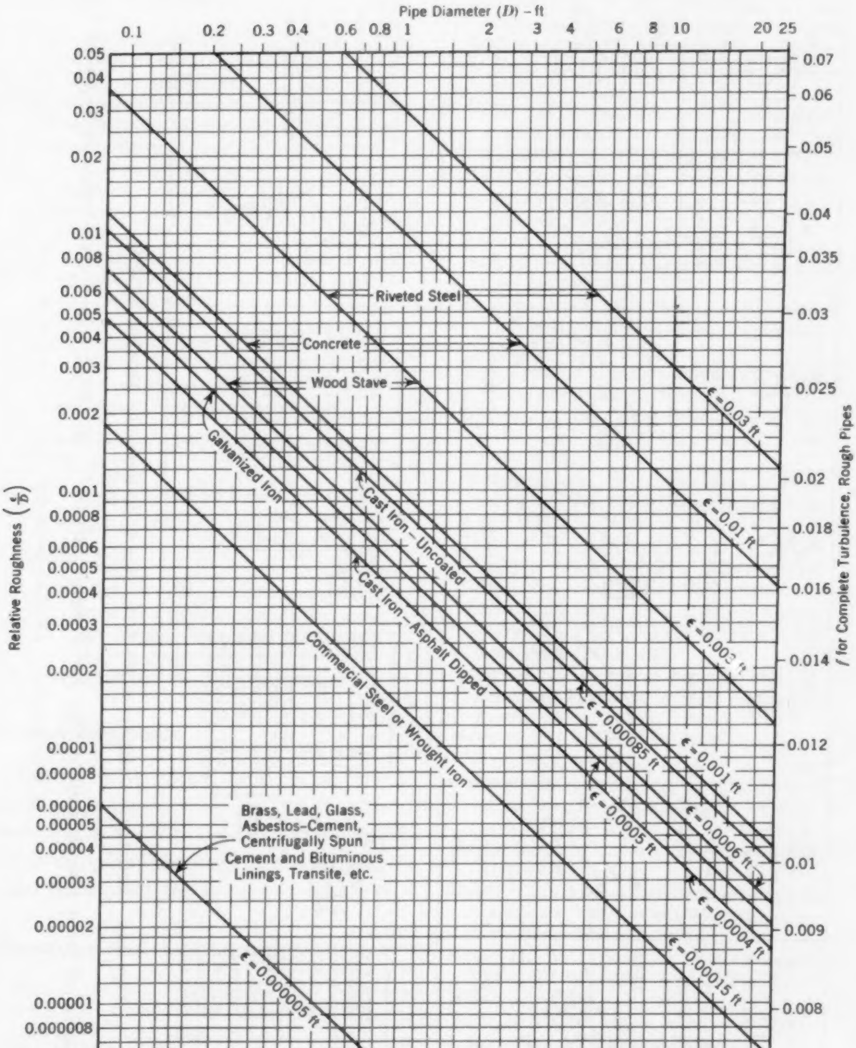
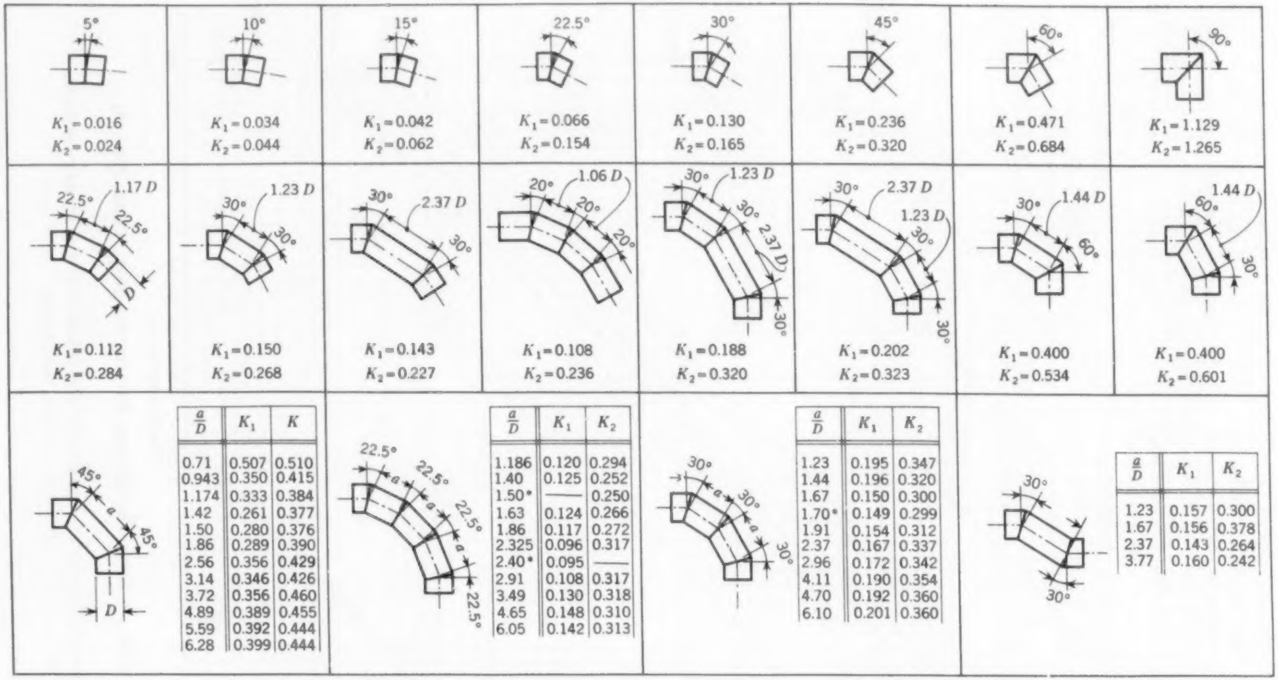


Fig. 5.13. Relative Roughness Factors for New, Clean Pipe (9)

The roughness factors are needed for the solution of the Moody formula.



$\frac{a}{D}$	K_1	K
0.71	0.507	0.510
0.943	0.350	0.415
1.174	0.333	0.384
1.42	0.261	0.377
1.50	0.280	0.376
1.86	0.289	0.390
2.56	0.356	0.429
3.14	0.346	0.426
3.72	0.356	0.460
4.89	0.389	0.455
5.59	0.392	0.444
6.28	0.399	0.444

$\frac{a}{D}$	K_1	K_2
1.186	0.120	0.294
1.40	0.125	0.252
1.50*	—	0.250
1.63	0.124	0.266
1.86	0.117	0.272
2.325	0.096	0.317
2.40*	0.095	—
2.91	0.108	0.317
3.49	0.130	0.318
4.65	0.148	0.310
6.05	0.142	0.313

$\frac{a}{D}$	K_1	K_2
1.23	0.195	0.347
1.44	0.196	0.320
1.67	0.150	0.300
1.70*	0.149	0.299
1.91	0.154	0.312
2.37	0.167	0.337
2.96	0.172	0.342
4.11	0.190	0.354
4.70	0.192	0.360
6.10	0.201	0.360

$\frac{a}{D}$	K_1	K_2
1.23	0.157	0.300
1.67	0.156	0.378
2.37	0.143	0.264
3.77	0.160	0.242

Fig. 5.14. Resistance Coefficients for Miter Bends at Reynolds Number 225,000

K_1 *is the resistance coefficient for a smooth surface;* K_2*, for a rough surface,* $\frac{\epsilon}{D} \cong 0.0022$. *In* $\frac{a}{D}$, *the optimum value of "a" is interpolated. (Figure from Ref. 9.)*

Hydraulic Symbols

A = area of pipe (sq ft)
C = general flow coefficient
C_c = Chezy coefficient
C_{hw} = Hazen-Williams coefficient
D = diameter of pipe (ft)
d = diameter of pipe (in.)
f = Darcy friction factor
F_m = Mills coefficient
g = acceleration of gravity (32.17 fps/sec)
H = head loss (ft) in pipe length L (ft)
H_s, H_m = head loss (ft) in 1,000 ft of pipe
k = ϵ (which see)
K_s = Scobey constant
L = Length of pipe (ft)
n = Kutter or Manning coefficient
$Q = AV$ = discharge (cfs)
r = hydraulic radius (ft)
$R = \frac{VD}{\nu}$ = Reynolds number
$s = \frac{H}{L}$ = slope of hydraulic gradient
V = mean velocity (fps)
x, y = exponents experimentally determined
ϵ, k = height of surface roughness or some linear dimension representing average height, form, and distribution of such projections (ft)
ν = kinematic viscosity (sq ft/sec)

Acknowledgments

Figures 5.11, 5.13, and 5.14 are reprinted, with permission, from the *Pipe Friction Manual* (*9*). Figure 5.12 is supplied through the courtesy of the Bureau of Reclamation (*4*).

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CHAPTER 6

Determination of Pipe Wall Thickness

THE wall thickness of steel pipe is affected by a number of factors which will be discussed in this and succeeding chapters:

1. Internal pressure
a. Static pressure (Chap. 6)
b. Surge or water hammer pressure (Chap. 7)
2. External pressure
a. Trench loading pressure (Chap. 8)
b. Earth fill pressure (Chap. 8)
c. Uniform collapse pressure, atmospheric or hydraulic (Chap. 6)
3. Special physical loading
a. Pipe on saddle supports (Chap. 9)
b. Pipe on ring girder supports (Chap. 9)
4. Practical requirements (Chap. 6).

The thickness selected will be that which meets the most severe requirement.

6.1. Internal Pressure

When designing for internal pressure, the engineer determines by formula the minimum thickness of a ring 1 in. long so that the tension stress in it does not exceed a certain level. This stress is frequently termed "hoop" stress.

The internal pressure used in design should be that to which the pipe is actually subjected. In a gravity flow line, the pressure is measured by the distance between the pipe centerline and the hydraulic gradient. If there are across-the-line valves, the maximum pressure on the pipe between them will be measured by the distance between the pipe centerline and the elevation of the static level with the valves closed.

In a pumping line, the pressure is measured by the distance between the pipe and the hydraulic gradient created by the pumping operation. Pressure at the outlet and the loss due to friction enter into this determination.

Surge or water hammer pressures must also be considered. These are discussed in Chap. 7.

With pressure determined, the wall thickness is found using Eq 6.1:

$$t = \frac{pd}{2s} \qquad (6.1)$$

in which:

t = wall thickness (in.)
p = pressure (psi)
d = outside diameter of pipe (in.)
s = allowable stress (psi).

The value of d used in Eq 6.1 should be the outside diameter of a commercially available or standard-size pipe selected after completion of the hydraulic calculations. Instead of using the equation, pipe can be selected directly from Table 6.2, which is based on it.

There are a number of formulas for determining the stress in the wall of a hollow cylinder of uniform thickness subjected to internal pressure (*1*). The principal stress is circumferential and is tension. It increases from a minimum on the outside surface to a maximum on the inside surface. The value of stress is given by the more

precise formulas whose accuracy has been verified experimentally. These stress values are higher than are predicted by an analysis based on static equilibrium existing between the internal pressure load and the circumferential tension in the pipe wall. To rectify this difference and still use a single formula, the assumption is made that the internal pressure acts on the outside diameter rather than on the inside diameter, although the latter condition is the true one. The wall thickness determined using Eq 6.1 is exact, for all practical purposes, for pipe having a diameter–wall thickness ratio of at least 50:1, which is common in water works service. In other words, Eq 6.1 is theoretically accurate when the pipe wall thickness is equal to or less than 2 per cent of the pipe diameter. For diameter–wall thickness ratios less than about 10:1, Eq 6.1 gives thicknesses which may be quite conservative and uneconomical.

6.2. Working Tension Stress in Steel

6.2.1. *Tension stress and yield strength.* There is an understandable and growing tendency to increase the allowable working stress for steel and to base this working stress on the yield strength of the steel rather than on its ultimate strength. For example, the American Standard Code for Pressure Piping (*2*) allows a working stress 0.48 times the specified yield strength for large, ordinary welded steel pipe in industrial-plant gas and air piping systems. Outside city limits, working pressures in oil and gas lines are permitted to be as high as 72 per cent of the yield strength. Allowable combined stresses are related to yield strength rather than ultimate strength.

A 1954 survey of 25 users of steel pipe, including cities, federal agencies, and consulting engineers, showed them employing an average design stress of 14,800 psi, and there was a quite consistent tendency toward 50 per cent of the specified minimum yield strength of the steel used.

A study of penstocks showed that, in the gross pipe wall section, ***under static head only***, the stress in welded pipe varied from 7,650 to 13,500 psi and for 65 installations averaged 10,300. Other investigations indicated that general practice in penstock design is to use a working tensile stress of 16,000 psi, considering ***static pressure plus surge pressure.***

TABLE 6.1

Grades of Steel Used as Basis for Working Pressures in Table 6.2

Specifications	Design Stress 50% Yield Point *psi*	Min. Yield Point *psi*	Min. Ultimate Tensile Strength *psi*
ASTM A415	12,500	25,000	48,000
ASTM A283 B	13,500	27,000	50,000
ASTM A283 C	15,000	30,000	55,000
ASTM A283 D	16,500	33,000	60,000
X42 grade of plate under API = 5LX	21,000	42,000	60,000

Table 6.2 has been prepared to give the designer working pressures corresponding to 50 per cent of the specified minimum yield strength of several steels used in water works practice, as shown in Table 6.1.

6.2.2. *Pressure limits.* High quality in the manufacture of both steel and pipe is required by AWWA standards. The hoop stress, therefore, may well be allowed to rise, within limits, above 50 per cent of yield for intermittent loads or loads

TABLE 6.2

*Working Pressures for Allowable Unit Stresses**

Nominal Size† *in.*	Wall Thickness‡ *in.*	Stress—*psi* 12,500	13,500	15,000	16,500	21,000	Collapse Pressure *psi*	Nominal Size† *in.*	Wall Thickness‡ *in.*	Stress—*psi* 12,500	13,500	15,000	16,500	21,000	Collapse Pressure *psi*
		Working Pressure—*psi*§								Working Pressure—*psi*§					
4	0.105	656	709	788			889	22	0.179	203	220				27
4	0.135	844	911	1,013			1,539	22	0.188	214	230	256	281		31
4	0.105	583	630	700			636	22	0.239	272	293	326	359		64
4½	0.135	750	810	900			1,214	22	0.250	284	307	341	375		74
6	0.135	563	608	675			572	22	0.313	356	384	426	469		144
6	0.188	783	844	938			1,329	22	0.375	426	460	511	563		249
6	0.219	913	985	1,094			1,778	24	0.179	186	201				21
6⅝	0.105	396	428	476			200	24	0.188	196	211	234	258		24
6⅝	0.135	509	550	612			425	24	0.239	249	269	299	329		50
6⅝	0.188	709	764	849			1,073	24	0.250	260	281	313	344	437	57
6⅝	0.219	826	892	991			1,479	24	0.313	326	352	391	430	546	111
8	0.105	328	354	394			114	24	0.375	391	422	469	516	656	191
8	0.135	422	456	506			241	24	0.438	456	492	547	602	765	304
8	0.179	559	604	671			562	24	0.500	521	563	625	688	875	454
8	0.188	588	633	703			651	26	0.179	172	186	207	227		16
8	0.219	684	730	821			986	26	0.188	181	195	216	238		19
8⅝	0.105	304	329	365			91	26	0.239	230	248	276	303		39
8⅝	0.135	391	423	470			192	26	0.250	240	260	289	318	404	45
8⅝	0.179	519	560	623			449	26	0.313	301	325	361	397	505	87
8⅝	0.188	545	587	652			516	26	0.375	360	389	433	476	605	151
8⅝	0.219	634	686	762			814	26	0.438	421	454	505	555	706	239
10	0.135	338	365	405			124	26	0.500	481	519	577	635	807	357
10	0.179	448	483	537			288	28	0.179	160	173	192	211		13
10	0.188	470	506	563			331	28	0.188	168	181	201	221		15
10	0.239	598	645	717			685	28	0.239	213	231	256	282		31
10	0.250	625	675	750			781	28	0.250	223	241	268	295	375	36
10¾	0.135	314	339	377			99	28	0.313	277	301	335	368	469	70
10¾	0.179	416	450	500			232	28	0.375	335	362	402	442	562	121
10¾	0.188	437	471	523			266	28	0.438	391	422	469	516	656	191
10¾	0.239	556	600	667			552	28	0.500	446	482	536	589	750	286
10¾	0.250	581	628	698			630	30	0.188		167	185	204		12
12	0.135	281	304	338			71	30	0.250		221	246	271	344	28
12	0.179	373	403	448			167	30	0.313		276	306	337	428	54
12	0.188	392	422	469			191	30	0.375		329	366	402	512	91
12	0.239	498	538	598			397	30	0.438		383	425	468	595	143
12	0.250	521	563	625			454	30	0.500		436	484	532	677	211
12¾	0.135	265	286	318			60	32	0.188		156	174	191		10
12¾	0.179	351	379	421			139	32	0.250		208	231	254	324	23
12¾	0.188	369	397	441			160	32	0.313		259	287	316	403	44
12¾	0.239	469	506	562			331	32	0.375		309	344	378	481	75
12¾	0.250	490	529	588			379	32	0.438		359	399	439	559	118
14	0.135	241	260	289			45	32	0.500		409	455	500	636	175
14	0.179	320	345	384			105	34	0.188		147	164	180		8
14	0.188	336	362	402	442		121	34	0.250		196	217	239	304	19
14	0.239	427	461	512	563		250	34	0.313		244	271	298	379	37
14	0.250	446	482	536	589		286	34	0.375		291	324	356	453	63
16	0.135	211	228	253	278		30	34	0.438		339	376	414	527	99
16	0.179	280	302				70	34	0.500		386	429	471	600	146
16	0.188	294	316	352	387		81	36	0.188		139	155	170		7
16	0.239	373	403	448	493		167	36	0.250		185	206	226	287	16
16	0.250	391	422	469	516		191	36	0.313		230	256	282	358	31
16	0.313	489	527	586	645		374	36	0.375		276	306	337	428	53
18	0.135	188	203	225	248		21	36	0.438		320	356	392	498	84
18	0.179	249	269				49	36	0.500		365	405	446	567	124
18	0.188	261	281	313	344		57	36	0.625		453	503	554	704	237
18	0.239	332	359	398	438		118	38	0.188		132	147	161		6
18	0.250	347	375	417	458		134	38	0.250		175	195	214	273	14
18	0.313	435	469	521	573		263	38	0.313		218	243	267	340	27
20	0.135	169	182	203	223		15	38	0.375		261	290	319	407	45
20	0.179	224	242				36	38	0.438		304	337	371	472	71
20	0.188	235	253	281	309		41	38	0.500		346	385	423	537	106
20	0.239	299	323	359	394		86	38	0.625		430	478	526	668	203
20	0.250	313	338	375	413		98	40	0.188		125	139	153		5
20	0.313	391	422	469	516		191	40	0.250		167	185	204	260	12
20	0.375	469	506	563	619		331	40	0.313		208	231	254	324	23

* Values have been computed by electronic calculator. See text for formulas used.
† Sizes under 30 in. are OD sizes; those 30 in. and over are ID sizes.
‡ Other wall thicknesses are available from some manufacturers.
§ Working pressures may be interpolated or extrapolated for other stresses or wall thicknesses.

TABLE 6.2—*Working Pressures for Allowable Unit Stresses** (*contd.*)

Nominal Size† *in.*	Wall Thickness‡ *in.*	Stress—*psi*: 12,500	13,500	15,000	16,500	21,000	Collapse Pressure *psi*
		Working Pressure—*psi*§					
40	0.375		249	276	304	387	39
40	0.438		289	321	353	449	61
40	0.500		329	366	402	512	91
40	0.625		409	455	500	636	175
42	0.188		120	133	146		4
42	0.250		159	177	194	247	10
42	0.313		198	220	242	308	20
42	0.375		237	263	290	368	34
42	0.438		276	306	337	428	53
42	0.500		314	349	384	488	79
42	0.625		390	434	477	607	151
45	0.250		148	165	181	231	8
45	0.313		185	206	226	287	16
45	0.375		221	246	271	344	28
45	0.438		258	286	315	400	44
45	0.500		294	326	359	456	64
45	0.625		365	405	446	567	124
48	0.250		139	155	170	216	7
48	0.313		174	193	212	270	13
48	0.375		208	231	254	323	23
48	0.438		242	269	295	376	36
48	0.500		276	306	337	428	53
48	0.625		343	381	419	532	103
48	0.750		409	455	500	636	175
51	0.250		131	146	160	204	6
51	0.313		163	182	200	254	11
51	0.375		196	217	239	304	19
51	0.438		228	253	278	354	30
51	0.500		260	289	317	404	45
51	0.625		323	359	395	502	86
51	0.750		386	429	471	600	146
54	0.250		124	138	151	193	5
54	0.313		155	172	189	240	9
54	0.375		185	206	226	287	16
54	0.438		215	239	263	335	25
54	0.500		246	273	300	382	38
54	0.625		305	339	373	475	73
54	0.750		365	405	446	567	124
57	0.250		117	130	144	182	4
57	0.313		146	163	179	228	8
57	0.375		175	195	214	273	14
57	0.438		204	227	250	318	22
57	0.500		233	259	285	362	32
57	0.625		290	322	354	450	62
57	0.750		346	385	423	537	106
60	0.250		112	124	136	174	4
60	0.313		139	155	170	217	7
60	0.375		167	185	204	260	12
60	0.438		194	216	237	302	19
60	0.500		221	246	271	344	28
60	0.625		276	306	337	428	53
60	0.750		329	366	402	512	91
60	0.875		383	425	468	595	143
60	1.000		436	484	532	677	211
63	0.250		106	118	130	165	3
63	0.313		133	147	162	206	6
63	0.375		159	177	194	247	10
63	0.438		185	206	226	287	16
63	0.500		211	234	258	328	24
63	0.625		263	292	321	408	46
63	0.750		314	349	384	488	79
63	0.875		365	405	446	567	124
63	1.000		415	462	508	646	183
66	0.250		102	113	124	157	3
66	0.313		127	141	155	197	5
66	0.375		152	169	185	236	9
66	0.438		177	196	216	275	14
66	0.500		202	224	246	313	21
66	0.625		251	279	307	390	40
66	0.750		300	333	367	466	69
66	0.875		349	388	426	542	108
66	1.000		397	441	485	618	160
69	0.250		97	108	119	151	2
69	0.313		121	135	148	189	5
69	0.375		145	161	177	226	8
69	0.438		169	188	207	264	12
69	0.500		193	214	236	300	18
69	0.625		240	267	294	374	35
69	0.750		287	319	351	447	60
69	0.875		334	371	408	519	95
69	1.000		380	423	465	591	140
72	0.250		93	103	114	145	2
72	0.313		116	129	142	181	4
72	0.375		139	155	170	216	7
72	0.438		162	180	198	252	11
72	0.500		185	206	226	287	16
72	0.625		230	256	282	358	31
72	0.750		276	306	337	428	53
72	0.875		320	356	392	498	84
72	1.000		365	405	446	568	124
75	0.250		89	99	109	139	2
75	0.313		112	124	136	174	4
75	0.375		134	149	163	208	6
75	0.438		156	173	190	242	10
75	0.500		178	197	217	277	14
75	0.625		221	246	271	344	28
75	0.750		265	294	324	411	47
75	0.875		308	342	376	478	74
75	1.000		351	390	429	545	110
78	0.250		86	96	105	134	2
78	0.313		107	119	131	167	3
78	0.375		129	143	157	200	5
78	0.438		150	166	183	233	9
78	0.500		171	190	209	266	13
78	0.625		213	237	260	332	25
78	0.750		255	283	311	396	42
78	0.875		296	329	362	461	66
78	1.000		338	375	413	525	98
81	0.250		83	92	101	129	1
81	0.313		103	115	126	161	3
81	0.375		124	138	151	193	5
81	0.438		144	160	176	224	8
81	0.500		165	183	201	256	11
81	0.625		205	228	251	319	22
81	0.750		246	273	300	382	38
81	0.875		286	317	349	444	59
81	1.000		325	361	398	506	88
84	0.250		80	89	98	124	1
84	0.313		100	111	122	155	3
84	0.375		120	133	146	186	4
84	0.438		139	155	170	217	7
84	0.500		159	177	194	247	10
84	0.625		198	220	242	308	20
84	0.750		237	263	290	368	34
84	0.875		276	306	337	428	53
84	1.000		314	349	384	488	79
87	0.250		77	86	94	120	1
87	0.313		96	107	118	150	2
87	0.375		115	128	141	180	4
87	0.438		134	149	164	209	6

* Values have been computed by electronic calculator. See text for formulas used.
† Sizes under 30 in. are OD sizes; those 30 in. and over are ID sizes.
‡ Other wall thicknesses are available from some manufacturers.
§ Working pressures may be interpolated or extrapolated for other stresses or wall thicknesses.

TABLE 6.2—*Working Pressures for Allowable Unit Stresses** (*contd.*)

Nominal Size† *in.*	Wall Thickness‡ *in.*	Stress—psi: 12,500	13,500	15,000	16,500	21,000	Collapse Pressure *ps*	Nominal Size† *in.*	Wall Thickness‡ *in.*	Stress—*psi*: 12,500	13,500	15,000	16,500	21,000	Collapse Pressure *psi*
		Working Pressure—*psi*§								Working Pressure—*psi*§					
87	0.500		153	171	188	239	9	93	0.375		108	120	132	168	3
87	0.625		191	213	234	298	18	93	0.438		126	140	154	196	5
87	0.750		229	254	280	356	31	93	0.500		144	160	176	224	8
87	0.875		266	296	325	414	48	93	0.625		179	199	219	279	15
87	1.000		303	337	371	471	71	93	0.750		214	238	262	333	25
90	0.250		75	83	91	116	1	93	0.875		249	277	305	388	40
90	0.313		93	103	114	145	2	93	1.000		284	316	347	442	59
90	0.375		112	124	136	175	4	96	0.250		70	78	86	109	1
90	0.438		130	144	159	202	6	96	0.313		87	97	107	136	2
90	0.500		148	165	181	231	8	96	0.375		105	116	128	163	3
90	0.625		185	206	226	287	16	96	0.438		122	136	149	190	5
90	0.750		221	246	271	344	28	96	0.500		139	155	170	216	7
90	0.875		258	286	315	400	44	96	0.625		174	193	212	270	13
90	1.000		294	326	359	456	64	96	0.750		208	231	254	324	23
93	0.250		72	80	88	113	1	96	0.875		242	269	295	376	36
93	0.313		90	100	110	140	2	96	1.000		276	306	337	428	53

* Values have been computed by electronic calculator. See text for formulas used.
† Sizes under 30 in. are OD sizes; those 30 in. and over are ID sizes.
‡ Other wall thicknesses are available from some manufacturers.
§ Working pressures may be interpolated or extrapolated for other stresses or wall thicknesses.

whose occurrence is a remote possibility. For steel pipe 18 in. and smaller, the limit of such rise should be 75 per cent of yield strength or the mill test pressure, whichever is the smaller. Under no circumstances should the specified hydrostatic mill or field test pressure induce a hoop stress exceeding 85 per cent of the specified minimum yield strength of the steel used.

6.3. Mill Tolerance

Steel pipe is sold on a nominal-thickness basis whether made from skelp at a pipe mill or from plate in a fabricating plant. The specified underthickness tolerance applies to this nominal thickness. Except in extremely high-pressure lines designed with great precision, the water works engineer need not concern himself with underthickness tolerance. It is usually an insignificant factor in a group of many estimated factors.

6.4. Corrosion Allowance

Adding a fixed rule-of-thumb thickness to the pipe wall as a corrosion allowance is not a rational solution of a corrosion problem. This is especially true in the water works field, where approved coating materials and coating procedures prevail. It is preferable to use the required nominal wall thickness pipe and then apply the proper protective coating for the condition encountered.

6.5. External Pressure—Uniform

Wall thickness must be selected to resist external loading properly. Such loading may take the form of outside pressure, either atmospheric or hydrostatic, both of which are uniform, radially acting collapse forces. Also, buried pipe must resist earth pressures in trench or fill. (Earth loading is discussed in Chap. 8.)

6.5.1. *General theory.* The general theory of collapse resistance of steel

pipe to uniform, radially acting forces has been developed (*3*). Any unreinforced tube longer than the critical length can be considered a tube of infinite length, as its collapsing pressure is independent of further increase in length. The following formula applies to such tubes:

$$p = \frac{2E}{1 - \mu^2}\left(\frac{t}{d}\right)^3 \quad \text{(6.2)}$$

in which:

d = diameter to neutral axis (in.) (for thin tubes, the difference between inside diameter, outside diameter, and neutral-axis diameter is negligible)
t = wall thickness (in.)
p = collapsing pressure (psi)
E = modulus of elasticity (30,000,000 for steel)
μ = Poisson's ratio (usually taken as 0.30 for steel).

Substituting the above values of E and μ:

$$p = 66{,}000{,}000\left(\frac{t}{d}\right)^3 \quad \text{(6.3)}$$

6.5.2. *General practice.* Circular cylindrical shells under external pressure may fail either by buckling or by yielding. Relatively thin-walled shells fail through instability or buckling under stresses that, on the average, are below the yield strength of the material. In the water works field, the thickness-diameter ratio is such that there is usually a buckling failure. Shells with relatively thick walls fail by plastic deformation under load. A number of theoretical and empirical formulas have been promulgated to provide for the effect of instability due to collapsing. They include the formulas of Timoshenko, Love, Roark, Stewart, and Bryan.

Stewart developed two empirical equations for the collapsing pressures of steel tubes based on tests. The Stewart formulas, which automatically account for wall thickness variations, out-of-roundness, and other manufacturing tolerances are:

For buckling failure, where $\frac{t}{d}$ is 0.023 or less and p is 581 psi or less:

$$p = 50{,}200{,}000\left(\frac{t}{d}\right)^3 \quad \text{(6.4)}$$

For plastic failure where values of $\frac{t}{d}$ and p are greater than above:

$$p = 86{,}670\left(\frac{t}{d}\right) - 1{,}386 \quad \text{(6.5)}$$

The Stewart formulas are considered more conservative than the previous formulas.

The collapse resistances given in Table 6.2, calculated using Eq 6.4 and 6.5, are predicated upon the pipe's being commercially round, made of steel with a minimum yield of at least 27,000 psi, and of a length six diameters or more between reinforcing elements. The figures would apply to simply supported exposed pipe subject to partial internal vacuum and may be used for air valve calculations. A safety factor (usually 1.5 or 2.0) should be applied to values in Table 6.2 to obtain design pressures.

Reinforcement of large steel pipe to resist external pressure is unusual. If required, however, design data on size and spacing of reinforcing members, maximum size of shell openings, and other details may be obtained from published sources (*4*).

6.6. Practical Requirements

The practical requirements that must be met may be based on the

following considerations: [1] the designer's own experience or preference; [2] organization practice or policy stemming from its experience; [3] a special set of circumstances affecting a particular installation, such as high hazard of operation or exposure to destructive elements; [4] the necessity to economize on cost; [5] the type of protective coating used (discussed in Chap. 8 and 13); and [6] the minimum practical thickness for handling and installing if other factors do not govern. For unstiffened pipe placed *aboveground* and not subject to inside vacuum, a rule is that the minimum thickness in inches is 0.0025 $(d + 20)$, d being diameter in inches.

6.7. Good Practice

Internal pressure, external pressure, special physical loading, and practical requirements govern wall thickness. Good practice with regard to internal pressure for pipe greater than 18 in. in diameter is to use a working tensile stress of 50 per cent of the yield point stress and to consider static pressure plus water hammer. But for a pipeline in which a maximum surge may rarely, if ever, occur—such as a pumping main where power failures occur only once or twice a year—the maximum allowable water hammer stress together with the static pressure stress possibly may be taken at 75 per cent of the yield point stress. The designer should, however, never overlook the effect of water hammer and surge in design. For internal pressure for pipe 18 in. and smaller, allowable hoop stress is indicated to be 50 per cent of the yield point strength for ordinary operation and not more than about 75 per cent for extraordinary intermittent load or for loads seldom apt to occur. It is better to protect against corrosion hazards than to add steel by rule of thumb.

References and Bibliography

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Pumping Stations, Pumps, and Appurtenances

AWWA Distribution Manual

A training course in water distribution has been prepared under the supervision of AWWA Committee 4260 M—Education. The document is being published in installments (April 1961 issue, p. 458), and will afterwards be made available as a separate volume.

THOSE water systems that can deliver their supply to the customers by gravity without pumping or with a minimum of pumping are indeed fortunate. The need for many costly facilities and many operating problems are eliminated or reduced if gravity flow can be utilized. In the great majority of systems, however, the supply, after it has been collected and processed, must be pumped into the distribution system. Often the supply has to be repumped one or more times at various points in the distribution system to maintain the required pressures in elevated areas or in outlying regions. The major pumping installations, however, are generally required at or near the site where the supply is processed.

In the design of the plant, equipment, and appurtenances to perform the pumping operations adequately, reliably, and efficiently it is necessary to determine:

1. The best location for the pumping operations
2. The best source of power
3. The conditions of operation and the capacities that will be needed
4. The best type of pump and prime mover for the conditions of operation.

Pumping Stations

Location of Facilities

The major pumping operations are usually conducted at the treatment or processing works near the source of supply, and the pumping equipment is usually incorporated in the same structures as the treatment facilities. Sometimes it becomes necessary to have two separate and distinct pumping operations: raw-water, or low-lift, pumping from the source of supply to and through the treatment works; and main-service, or high-lift, pumping to take the treated water from a clear water basin or suction well and pump it to the distribution system. In the high-lift station, different sets of pumps may be needed to pump against different pressures to separate and distinct service areas. If so, the main station may have general, or main-service, pumps and booster, or high-service, pumps.

If wells are the main auxiliary sources of supply, they may either be located together at one point or at a number of points in the distribution system. If at one point, the supply is usually brought together and pumped, with or without treatment other than chiorination, directly to the distribution system. If spread out in the distribution system, the well supplies are generally pumped directly into the system. The pumps may have automatic controls or be controlled from one central operating point.

Architectural Treatment

Wherever they are located, the pumping station structures should be architecturally pleasing and the grounds should be well maintained. Although the cost of such enhancement may play a part in the extent to which it is carried on, pumping stations and the processing works are about the only parts of the water supply system visible to the general public.

In the design and layout of the building, attention should be given to the space requirements and proper location of the various facilities to be housed in it, and heating, lighting, ventilation, drainage, and interior decoration should be properly considered. Buildings should be constructed of fireproof materials. Careful thought should be given to provisions for future expansion.

Sources of Power

In the construction of a new pumping plant, the various available sources of power should be carefully studied to determine the best ones to use. The principal types of prime movers used in pumping operations are steam-driven engines; hydraulic turbines; electric motors; and oil-, gas-, or gasoline-driven internal-combustion engines. All of these are commonly used for furnishing the power necessary for the pumping operations. Which one is selected depends upon numerous factors, and careful study should be given to availability and reliability of the power source, and the economics of the installation, operation, and maintenance of the facilities required. Frequently, more than one source is used in a single station to provide greater reliability.

In the early days of water service, steam was the only, or at least the first, source of available power. Steam engines were among the first to be developed, coal and labor were cheap, and the operating costs were low. Water power also was one of the first sources used for pumping, where it was available. Both of these sources were, and still are, among the most reliable.

As a result of the steeply rising costs of labor and coal and the development of increasingly reliable transmission of electric power from large, efficient central power stations, electricity has gradually taken over most of the task of water pumping. In some of the larger pumping installations,

steam may still be the most advantageous source, but in medium and small plants electricity has rapidly become the chief source of power.

In certain localities, favorably situated near the sources of fuel supply, oil- or gas-driven internal-combustion engines may prove to be the most logical and economical prime movers. They are very frequently used to provide standby capacity in a major steam or electric-power installation.

Energy Used in Pumping

Energy must be expended in pumping water to produce velocity in the water, to lift it, if necessary, from a storage receptacle to the pump, to provide sufficient pressure to raise it to a higher elevation, and to overcome the frictional resistances to flow in the piping system.

The energy required to produce velocity is transformed to pressure energy according to the formula for velocity head, $h = V^2/2g$, in which h is head, V is velocity, and g is the acceleration due to gravity.

If Q is the volume of water moved and W is the weight of a unit volume, the work required to produce V is $QWV^2/2g = QWh$.

If h_1 is the height (in feet) which the water must be raised (including suction lift if necessary) and h_2 is the friction head, then the total work done (in foot-pounds) by a pump will be $QW(h + h_1 + h_2)$.

Work is the overcoming of resistance by a force acting through space. Power is the rate of work; it is the product of force and distance divided by time. A certain amount of power is required to pump a certain quantity of water against a certain pressure or head in a given time.

Not all energy applied to mechanical devices is fully utilized. Certain losses—such as electric loss, friction losses, and velocity losses—which occur in the machines or their appurtenances must be included to determine the total amount of power to be applied in order to do the useful work. The ratio of the useful work resulting from the power applied is referred to as the *efficiency* (E) of the machine, expressed as a percentage.

The formula for determining the horsepower, R, to be applied in pumping is $R = QWH/PE$, in which Q is the pumpage in gallons per minute, W is the unit weight, in pounds, of the liquid pumped, H is the total head, in feet, P is the work done, in foot-pounds, by 1 hp in 1 min, and E is the efficiency in per cent. Thus, for water the formula becomes:

$$R\ (\text{hp}) = \frac{8.33 \times Q\ (\text{gpm}) \times H\ (\text{ft})}{33{,}000 \times E\ (\%)},$$

or

$$R\ (\text{hp}) = \frac{Q\ (\text{gpm}) \times H\ (\text{ft})}{3{,}960 \times E\ (\%)}.$$

It often becomes necessary to convert one type of power to another. Table 3.1 gives the common equivalent units of power.

Any prime mover may be used by proper connection to a suitable water pump. Energy losses—and, therefore, the efficiency of the unit—depend on the type of design, construction, and operation of the particular machine used. Table 3.2 gives an indication of the ranges of efficiency in various types of pumping equipment.

Types and Classifications of Pumps

Pumps commonly used for water service may be classified according to: (1) mode of action, whether piston, plunger, centrifugal, rotary, jet,

TABLE 3.1

Power Unit Equivalents

Work *ft-lb/min*	Mechanical Power *hp*	Heat *Btu/min*	Electric Power *w*	Water Power *ft-gal/min*
1	0.0000303	0.001285	0.0226	0.12
33,000	1	42.416	746	3,960
778	0.02357	1	17.58	93.28
44.24	0.00134	0.0568	1	5.308
8.33	0.00025	0.0107	0.18856	1

TABLE 3.2

Ordinary Efficiencies of Various Types of Pumping Equipment

Equipment Type	Efficiency *per cent*		Equipment Type	Efficiency *per cent*	
	Low	High		Low	High
Water wheels			Internal-combustion engines		
Turbine	75	90	Gasoline	15	25
Impulse wheel	75	90	Diesel or gas	25	30
Boilers	50	80	Pumps		
			Centrifugal	60	90
Steam engines			Mixed-flow	75	90
Triple expansion,			Axial-flow	70	86
condensing	15	20			
Compound, condensing	12	15	Electrical equipment		
Compound, noncondensing	7	9	Generators	80	95
			Motors, large	92	95
Steam turbines, condensing	12	22	Motors, small (<50 hp)	80	90
			Transformers	96	99

or direct pressure; (2) motive power, whether engine drive, turbine drive, motor drive; (3) number of cylinders (if applicable), whether simplex, duplex, or triplex; (4) number of stages or pump elements in series, whether single, double, or multistage; and (5) mode of connection, whether direct, belt, crank, or gear.

Piston and plunger pumps were once the most common types of pumps used with steam or internal-combustion engines. Rotary pumps, injector or jet pumps, and direct-pressure pumps, such as the pulsometer, ram, and air-lift pumps, were largely used for special purposes. Few, if any, of these types of pumps are now being installed in water systems.

Centrifugal Pumps

Because it so successfully fills the requirements of water works service, the centrifugal pump in its several variations has almost completely displaced all other types of pumping equipment. It is most commonly driven by an electric motor, but hydraulic and steam turbines and internal-combustion engine drives are frequently used.

The centrifugal pump consists essentially of a rotating impeller which draws water into its center and a stationary casing which guides the water to the discharge outlet. It may have a single or double suction arranged for end, bottom, or side suction piping connections. It may have an open, semiclosed, or closed impeller and be arranged for direct-connected horizontal or vertical drive, the latter being of either the dry-pit or submerged type. One or more single-stage pumps may be set in series with one driver, or the casing may be built to contain two or more impellers in order to pump against higher head. The casing of the pump may be in the form of a spiral or volute of constant cross section or be equipped with a diffuser.

In the true centrifugal pump, the pressure is developed principally by the action of centrifugal force. Two other similar types of pumps used for specific purposes are the mixed-flow pump, in which the head is developed partly by centrifugal force and partly by the lift of the vanes on the water, and the axial-flow pump, sometimes referred to as a propeller pump, in which most of the head is developed by the propelling or lifting action of the vanes on the water.

The centrifugal pump is used for high-head pumping in single or multistage arrangement. The mixed-flow and axial-flow pumps are adapted for low head, usually for large-capacity requirements. An adaptation of the normal arrangement of a centrifugal pump and its driver, used in the smaller capacities (3 mgd or less), is the close-coupled pump in which the pump is located on an extension of the motor shaft without independent support.

The principal operating features of a centrifugal pump and its advantages and disadvantages are: (1) low first cost; (2) compactness; (3) ab-

sence of valves and pistons; (4) low maintenance cost and low rate of depreciation; (5) smooth flow and uniform pressures; (6) simplicity of design and ease of operation and repair; (7) freedom from shock injury; (8) high rotating speed with direct connection to turbines or motors possible; (9) ability to handle dirty water; (10) increased output with pressure drops, and vice versa; (11) low starting torque; and (12) adaptability of automatic and semiautomatic control.

Capacity and Selection of Pumps

Generally, the main pumping station should be capable of furnishing the peak demand with the largest pumping unit out of service. If there is more than one pumping station, or if the demands can be met from more than one point (by storage, well supplies, or other means), system reliability is thereby increased and the number of additional units or other power sources needed for standby service may be somewhat reduced.

Determination of maximum demands is generally made by adding the necessary fire flow to the maximum-day demand. The NBFU specifies *:

> Pumping capacity shall be sufficient, with the two most important pumps out of service, to maintain the maximum daily consumption rate plus required fire flow at required pressure. For municipalities requiring less than 5,000 gpm fire flow, the relative infrequency of fires is assumed as offsetting in part the probability of a serious fire occurring at times when pumps are out of service, and allowance will be made accordingly.
>
> Where storage is provided, its ability to maintain supply with one pump and two pumps out of service shall be considered. To have no deficiency, pumps and storage shall be able to provide required fire flow for the specific duration during a period of 5 days with consumption at the maximum daily rate.

In addition to the reliability of pumps, deficiency points are assessed by NBFU on the basis of the reliability of power supply, plant equipment, pumping station, and piping.

It is well to provide a sufficient number of pumping units of suitable capacity to insure both reliability and sufficient flexibility to meet the varying requirements efficiently. The units should be designed to operate with the highest efficiency and greatest economy under normal conditions.

Centrifugal pumps operate most efficiently at one point on their head-capacity curve. When the head varies, the capacity varies, and the horsepower requirements and efficiency of the unit likewise vary. A typical set of characteristic curves for a centrifugal pump is illustrated in Fig. 3.1. The abscissa (horizontal scale) represents the quantity, generally in gallons per minute, and the ordinate (vertical scale) represents the head (in

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* *Standard Schedule for Grading Cities and Towns of the United States With Reference to Their Fire Defenses and Physical Conditions.* Natl. Board of Fire Underwriters, New York (1956). p. 22.

feet), the horsepower requirement, and the efficiency (in per cent). The operation of the pump under varying conditions of head and quantity can be determined from such a characteristic curve.

The effect of operating two or more centrifugal pumps in parallel against a certain station head produces an increase in head and, thereby, a decrease in capacity. Figure 3.2 illustrates the effect of the operation of three pumps singly and in parallel against a station head. It illustrates the

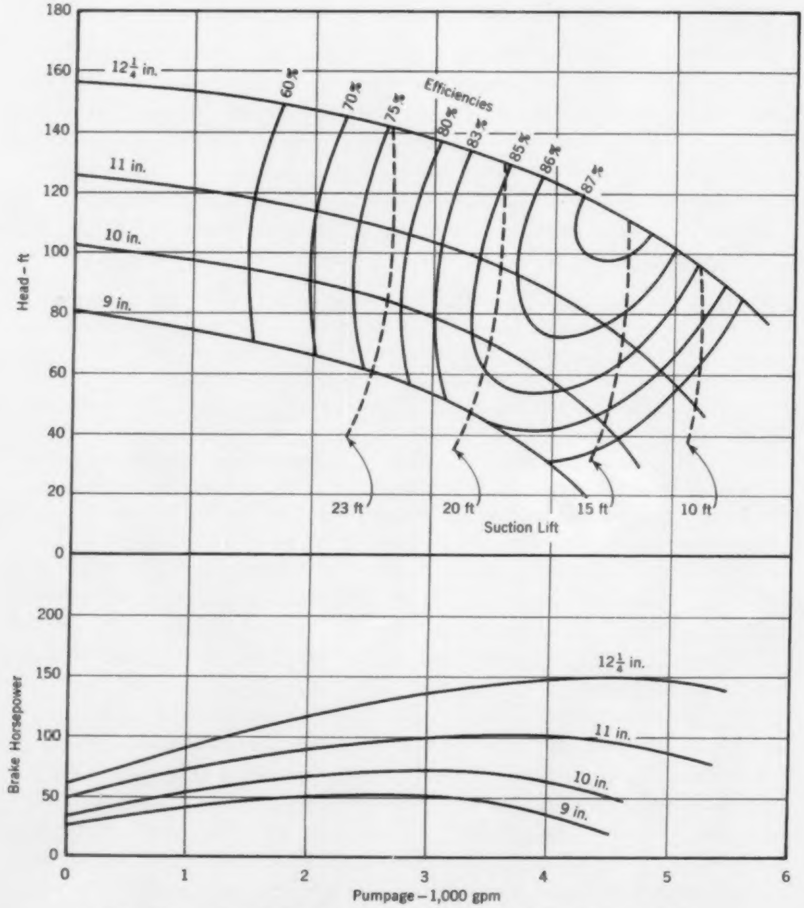

Fig. 3.1. Characteristic Curves, 1,760-rpm Centrifugal Pump

Shown are characteristic curves and brake horsepower curves for 12 × 12-in. 1,760-rpm centrifugal pumps with 9-, 10-, 11-, and 12¼-in. impellers.

effect of the reduced head upon pump operation. From the head-capacity relation, it is possible to determine the efficiency of the unit.

Prime Movers and Controls

The principal prime movers used for pumps in the water supply field are steam and hydraulic turbines, internal-combustion engines, and electric motors. Steam and hydraulic turbines are still a reliable and efficient power source, particularly for larger installations, but because of the limited use of such prime movers in the smaller and medium-size pumping installations and because of the high cost and complexities of the turbine and accompanying boiler plant, no attempt is made to cover such units in this manual. Qualified technical assistance should be sought for the design, installation, operation, and maintenance of turbine-driven pumping units.

Internal-Combustion Engines

Internal-combustion engines are frequently used in pumping plants, particularly in those areas where the unit costs of oil or gas are low. They are more often used in major plants as standby units for emergencies. The internal-combustion units employed for water pumping are generally stationary gasoline engines similar to those commonly used in other types of manufacturing processes. They are not so satisfactory for continuous operation, because of high maintenance costs, but they are admirably suited for standby service.

For more frequent use, the diesel engine is to be preferred over the less expensive gasoline engine, particularly since the development of small, self-contained units. Like other internal-combustion engines, however, they are more generally used to augment other kinds of motor-driven equipment or for standby service.

Electric Motors

The electric motor has largely replaced other means of driving pumping units, particularly in conjunction with the use of the centrifugal pump. The prevalence of cheap and dependable power, the availability of automatic and semiautomatic controls, the ease of operation and the reduced manpower needed, the small space requirements, and the mechanical and hydraulic reliability of electric motors and centrifugal pumps have all promoted the almost universal use of electric-motor-driven centrifugal pumps in water works practice.

Three types of electric motors are predominantly used in modern pumping installations: the squirrel cage motor, the wound-rotor (or slip-ring) motor, and the synchronous motor.

Perhaps the least expensive, simplest, and most reliable type of motor is a three-phase, squirrel cage motor. The squirrel cage type is used for constant-speed service. It draws a large starting current from the line. In sizes smaller than 1 hp, it is usually necessary to use single-phase motors, of which the capacitor type is the simplest and most reliable. This type of motor may also have to be used in larger sizes in areas where three-phase power is not available. For motors larger than 50 hp, the use of 220-v power requires large wire sizes, for which reason a 440-v power supply is preferable until the motor size exceeds 200–250 hp. In sizes larger than 250 hp, the combined cost of motor and starter may be less if a higher voltage, such as 2,300 v, is used.

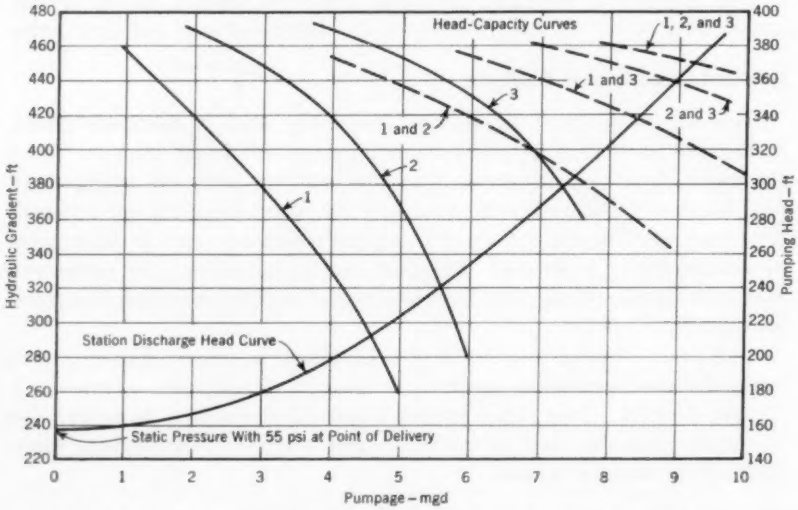

Fig. 3.2. Effect of Operation of Three Pumps Singly and in Parallel Against a Station Head

In an installation where there is some question as to the proper voltage to use, prices of motors and starters should be obtained for more than one voltage and comparisons should be made. Consideration should also be given to the larger wire sizes required for lower voltages.

Squirrel cage motors operate at constant speed—either 3,500 rpm, 1,750 rpm, 1,150 rpm, or slower. In general, low-capacity, high-head pumps operate at high speed, whereas low-head and large-capacity pumps operate at slower speeds. The speed of the unit is selected by the manufacturer to suit the combination of head and capacity of the particular pump.

The capacity of a pump can be varied by modifying its speed, although it is usually not necessary except under special conditions. Wound-rotor motors, called "slip ring" motors, can be operated at reduced speeds. In

this type of motor an across-the-line starter connects the power line to the stationary coils, and the coils in the rotor are fed through collecting rings and through resistors, the adjustment of which changes the motor speed. Such motors can be brought up to speed very gradually and their speed can be changed as desired, depending upon the number of resistors provided. Such an installation is relatively expensive and less efficient, because the speed reduction is brought about by dissipation of energy through the resistors. Such installations were formerly used frequently because of power company requirements, but their use is less frequent nowadays. Another possibility for speed regulation is a two-speed squirrel cage motor with a dual starter so that it can be operated, for example, at 3,500 and 1,750 rpm or 1,150 rpm and 820 rpm. Such speed changes result in a marked change in the pump capacity, for which reason such an installation can seldom be used. Variable-speed couplings are sometimes used.

TABLE 3.3

Typical Electric-Motor Efficiencies Under Full and Three-Quarter Load

Power Rating *hp*	Squirrel Cage		Slip Ring		Synchronous	
	¾ Load	Full Load	¾ Load	Full Load	¾ Load	Full Load
	Efficiency—*per cent*					
30	90	90			87.7	89.5
75	91	91	90	90	90.2	91.6
150	91.5	92	90.5*	90.5*	91.6 93.7	92.8 94.9
200	92	92.5	90.5*	90.5*	92.1 94.1	93.2 95.2

* Premium efficiency.

For pumps of 150 hp or more, synchronous motors may be desirable because they are more efficient than squirrel cage motors and their use reduces the power cost in many power company schedules. The total reduction in power cost may justify the substantially greater cost of the synchronous motor and its complicated and expensive starter.

The power factor of the pumping station may also be increased by the installation of capacitors. The use of capacitors, of course, hinges upon whether the power company's rate schedule offers sufficient incentive in reduced power cost to warrant the investment.

Power rate schedules frequently offer an inducement for taking power at a higher voltage as, for example, at 2,300 v instead of 440 v. The reduction in power cost may be sufficient to justify the slightly higher cost of high-voltage motors and starters.

The approximate efficiencies of the three kinds of motors under three-quarter and full load are shown in Table 3.3.

Starters

The simplest and least expensive starter is the across-the-line starter where full line voltage is applied to the motor terminals to start the motor. A squirrel cage motor draws many times its normal running current at the instant the starter is closed and while the motor is beginning to rotate. This sudden large draft may reduce the voltage on the power lines momentarily, causing lights of nearby consumers to flicker and, in extreme cases, interfering with operation of other equipment. This occurs particularly when the capacity of the power lines is limited, and under such circumstances the power company might not permit across-the-line starting. In some cases, the company may limit it to motors as small as 10 hp, whereas in other cases it may permit across-the-line starting on 1,000 hp. The power company should therefore be consulted in advance of installation.

If across-the-line starting is not permitted, then a reduced-voltage starter must be provided. In such a starter, the voltage applied to the motor terminals at the instant of starting may be reduced by resistors or reactors or by auto transformers, devices which are removed from the circuit when the motor approaches full speed. Because starters have more moving parts and, therefore, are both less reliable and more expensive, they are to be avoided if possible.

For most single-phase motors of approximately 1 hp, a toggle switch starter is the simplest and least expensive. Larger across-the-line starters are of the magnetic type in which the contacts are closed by an electromagnet actuated by a pushbutton switch, or some such device. The electromagnet closes the contacts quickly and firmly and holds them closed while the motor is operating.

A pressure switch, time switch, float switch, or other suitable automatic device can be inserted in the electromagnet control circuit. Reduced-voltage starters have several sets of contacts and, if magnetically operated, require several sets of magnets and a more complicated control circuit. If a motor can be started manually, such starters are less expensive than magnetic ones, although larger starters are almost all magnetically operated.

Because some abnormal operating condition may increase the load on the motor to more than its design capacity, the starters are equipped with overload relays to prevent the motor from burning out. The current flowing through the motor goes through heaters which open the control circuit and stop the motor when the current is excessive. Single-phase motors have one such overload relay, and three-phase motors have two or three overload relays. These relays are normally set to stop the motor when the current exceeds the design load by 25 per cent. The overload relays

are rather sensitive and heat up slowly; they are thus not well suited for protecting the motor against a short circuit. To protect against short circuits, there is a fuse in each line to the motor. These fuses are normally located in the safety switch which is installed just ahead of the starter. By opening the safety switch the starter can be de-energized for inspection or repair. The safety switch can be combined with the motor starter in so-called combination starters. These save space and field wiring, although they cost slightly more than separate safety switches and starters. When there are a number of motor starters and other devices at one location, a

TABLE 3.4

Types and Classifications of Liquid Meters

Quantity meters:

1. Weighing
   a. Tilting trap
   b. Weighing tank
2. Volumetric
   a. Nutating disc
   b. Reciprocating piston
   c. Rotary piston
   d. Tank

Rate meters:

1. Head (kinetic)
   a. Nozzle
   b. Orifice
   c. Pitot tube
   d. Venturi

Rate meters (contd.):

2. Area (geometric)
   a. Cone and disc
   b. Cylinder and piston
   c. Gate
   d. Orifice and plug
3. Head-area
   a. Flume
   b. Weir
4. Velocity
   a. Cup
   b. Propeller
   c. Turbine
5. Special
   a. Salt velocity
   b. Titration

control center consisting of standardized steel compartments in which motor starters and other devices of various sizes are assembled may be provided. Control centers are more expensive than the individual switches and starters, but they minimize space requirements, bring all devices together at one point, and substantially reduce the amount of field wiring.

Installation and Testing of Pumps

Centrifugal pumps, if properly installed and given reasonable care and maintenance, will operate satisfactorily and efficiently for long periods of time. The pump should be located as close as possible to the water source so that a short, direct-suction pipe may be used. Similarly, the discharge pipe should be as direct and short as possible to minimize friction losses. The pump should be accessible from all sides and, if it is a large unit, a crane or hoist should be available to facilitate handling. The pump should be protected against flooding, and, if motor driven, should be installed in

a dry, ventilated location. In any motor installation, adequate ventilation should be provided to dissipate heat losses.

Foundation and Alignment

The foundation should be sufficiently substantial to absorb vibration and to form a permanent, rigid support for the base plate to maintain alignment. In erecting a motor-driven unit, if it is factory mounted on a single base plate, the unit should be realigned on the foundation and carefully leveled on metal blocks or shims $\frac{3}{4}$ to $1\frac{1}{2}$ in. high to allow for grouting between the base plate and foundation. A flexible coupling to compensate for temperature changes should be provided between pump and driver but left uncoupled during the alignment process. After careful alignment, the foundation bolts should be tightened evenly but not too firmly, the unit grouted to the foundation, and the base plate completely filled with grout. After the grout has hardened properly, the foundation bolts can be firmly tightened. A final check on alignment and direction of rotation should be made before the coupling halves are connected and the unit is run. After running for a week or so, the alignment should again be rechecked and corrected, if necessary, whereupon both pump and motor should be doweled to the base plate.

Piping and Valves

The suction and discharge piping, header piping, and valve arrangement should be properly designed. The suction piping, in particular, must be carefully installed. It should have a gradual rise to the pump without any high spots to trap air, and it must be free of air leaks. Eccentric reducers should be used to prevent the formation of air pockets. Valves should not be used on suction lines if they can be avoided; if used, care should be taken that stem packing is tight against air leakage. Bends in suction lines should be avoided, particularly close to the pump.

Centrifugal pumps have a certain tolerance for suction lift. Although at sea level a maximum suction of approximately 34 ft is possible, in practice it is well to have less than half of this for proper operation. The effect of suction lift on a centrifugal pump is related to its head, capacity, and speed. The relation of these is expressed by an index number known as the specific speed. For a given head and capacity, a pump of low specific speed will operate safely with a greater suction lift than one of higher specific speed. If the suction lift is very high (more than 15 ft), it is often necessary to use a slower speed and a larger pump. Abnormally high suction lifts usually cause serious reductions in capacity and efficiency and may lead to serious trouble from vibration and cavitation.

Cavitation results from the formation of a void, or series of voids, within a body of liquid caused by the inability of the liquid particles to follow the

path of a perfect fluid. The voids become bubbles filled with vapor drawn from the liquid. A mechanical shock somewhat like water hammer results when these bubbles collapse. Cavitation not only causes vibration and noise but pitting of metal surfaces which ultimately damages or destroys pump parts.

Priming

Centrifugal pumps have water-, oil-, or grease-lubricated bearings and seals between stationary and rotating elements which require periodic attention. The pump casing and suction piping must be filled with water before the pump can become effective. It should never be run otherwise. Priming can be accomplished by an ejector, or vacuum pump, or the suction piping can have a foot valve which will allow the pump and piping to be filled with water. Often a high-pressure water ejector or exhauster combined with a wet-vacuum pump is provided for priming major units.

Testing

Testing of centrifugal pumps should be done by qualified technicians under the standards promulgated by the Hydraulic Institute and association of recognized pump manufacturers. Because it is advisable, however, that some of the terms used in the analysis of centrifugal-pump operation be recognized, a few of them are defined below:

Total suction lift. Suction lift exists when the total suction head is less than atmospheric pressure. It is the reading of a liquid manometer at the suction nozzle of the pump, converted to feet of water and referred to datum, minus the velocity head at the point of attachment. It is equivalent to the static lift plus entrance and friction losses in the piping plus the velocity head.

Suction head. Suction head exists when the total head is greater than atmospheric pressure. It is the reading of a gage at the suction nozzle of the pump, converted to feet of water and referred to datum, plus the velocity head at the point of attachment. It is equivalent to the static head less entrance and friction losses in the piping minus the velocity head.

Total discharge head. Total discharge head is the reading of a pressure gage at the discharge of the pump converted to feet of water and referred to datum plus the velocity head at the point of gage attachment.

Total head. Total head is the algebraic sum of the total discharge head and the total suction lift or suction head, suction lift being positive and suction head negative.

Driver input. The driver input, R_I, is the electrical input to the driver expressed in horsepower.

Pump input (brake horsepower). Pump input is the horsepower delivered to the pump shaft, designated as brake horsepower, R_B.

Pump output. Pump output is the water horsepower, R_W, delivered by the pump.

Efficiency. Pump efficiency, E_p, is the ratio of the water horsepower to the brake horsepower expressed as a percentage, according to the formula,

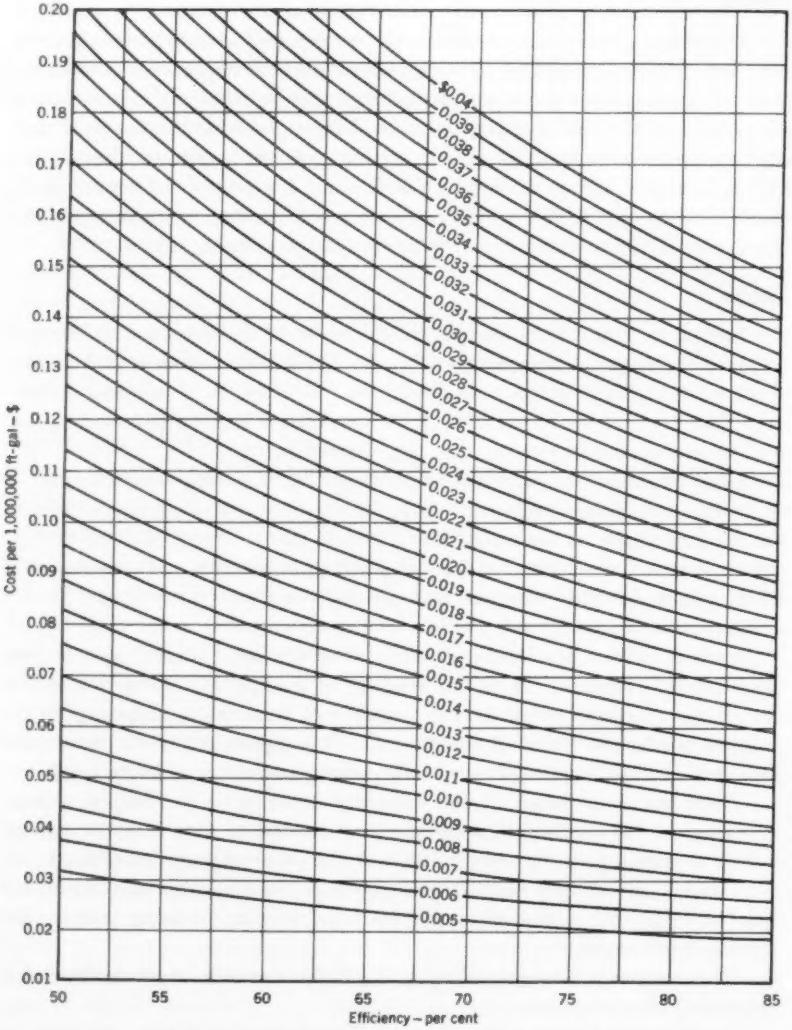

Fig. 3.3. Cost of Pumping at Various Unit Costs for Electric Power

$$E_p = \frac{R_W}{R_B} \times 100$$

Overall efficiency (E_o) is the ratio of the liquid horsepower to the input expressed as a percentage:

$$E_o = \frac{R_W}{R_I} \times 100$$

Overall efficiency is also the product of the pump efficiency and the motor efficiency.

Measurement of Flow

At any pumping station it is necessary to measure the amount of water pumped in order to obtain and keep a record of the water produced. Table 3.4 illustrates the various means of measurement of water divided into quantity measurement and rate of flow measurement.

The types of liquid meters preferred for use in determining the output of pumping stations or individual pumps are the venturi and orifice meters, which utilize head differentials, and the propeller or turbine velocity meters. Within the range of flows these meters are designed to cover, they will generally register within 2 per cent of the rated capacity. The registers accompanying the meters can be equipped to indicate, record, and integrate the flows in any combination and can be calibrated in gallons or cubic feet. They can be read directly or can be equipped to be read at remote distances.

Water Hammer

In any pump installation, attention should be given to water hammer. Water hammer is the oscillation in water pressure in a closed conduit resulting from sudden changes in the velocity of flow. Such changes may be caused by the sudden closing of a valve, such as frequently occurs in house plumbing and results in sharp knocks in the pipeline. It may be caused by the shutting down of a pump, either in normal operation or when the power goes off. Water, being virtually incompressible, forms a column in a pipeline which continues in motion even after the power that pushes it is relaxed. The pressure waves set up travel back and forth in the closed conduit causing fluctuations in pressure, which can be dangerous.

To protect the pump installation, a check valve is inserted on the discharge side which closes against the back surge of pressure and prevents water from going back through the pump. In large installations, it becomes necessary to provide special valves, such as automatic cone valves constructed to close slowly in order to reduce the pressure waves, or some means of surge suppression which will prevent, relieve, or absorb the shock

or water hammer. Water hammer is a highly complex phenomenon and the assistance of a hydraulic expert is required for its proper analysis and prevention.

Operation Checks and Controls

The proper operation and control of pumping stations, pumps, and appurtenances form an essential part of water utility operation. Even the best facilities cannot produce desirable results unless properly operated and maintained.

TABLE 3.5

Possible Causes of Operation Difficulties With Centrifugal Pumps

1. Pump not primed
2. Pump or suction pipe not completely filled
3. Suction lift too high
4. Insufficient margin between suction pressure and vapor pressure
5. Excessive amount of air or gas in liquid
6. Air pocket in suction line
7. Air leaks into suction line
8. Air leaks into pump through stuffing boxes
9. Foot valve too small
10. Foot valve partially clogged
11. Inlet of suction pipe insufficiently submerged
12. Water-seal pipe plugged
13. Seal cage improperly located in stuffing box, preventing sealing fluid from entering space to form seal
14. Speed too low
15. Speed too high
16. Wrong direction of rotation
17. Total head of system higher than design head of pump
18. Total head of system lower than pump design head
19. Specific gravity of liquid different from design
20. Viscosity of liquid differs from that for which designed
21. Operation at very low capacity
22. Parallel operation of pumps unsuitable for such operation
23. Foreign matter in impeller
24. Misalignment
25. Foundations not rigid
26. Shaft bent
27. Rotating part rubbing on stationary part
28. Bearings worn
29. Wearing rings worn
30. Impeller damaged
31. Casing gasket defective, permitting internal leakage
32. Shaft or shaft sleeves worn or scored at packing
33. Packing improperly installed
34. Incorrect type of packing for operating conditions
35. Shaft running off center because of worn bearings or misalignment
36. Rotor out of balance, resulting in vibration
37. Gland too tight, resulting in no flow of liquid to lubricate packing
38. Failure to provide cooling liquid to water-cooled stuffing boxes
39. Excessive clearance at bottom of stuffing box between shaft and casing, causing packing to be forced into pump interior
40. Dirt or grit in sealing liquid, leading to scoring of shaft or shaft sleeve
41. Excessive thrust caused by mechanical failure inside pump or by failure of hydraulic balancing device, if any
42. Excessive grease or oil in antifriction bearing housing or lack of cooling, causing excessive bearing temperature
43. Lack of lubrication
44. Improper installation of antifriction bearings (damage during assembly, incorrect assembly of stacked bearings, use of unmatched bearings as a pair)
45. Dirt getting into bearings
46. Rusting of bearings due to water in housing
47. Excessive cooling of water-cooled bearing, resulting in condensation in bearing housing of moisture from atmosphere

Operation Checks

In starting an electric-motor-driven centrifugal pump, the following rules of procedure should be observed:

1. Check the lubrication.
2. Prime the pump and make sure that the pump and suction piping are free of air.
3. If power is limited, reduce current surge on startup by starting the pump with the discharge valve closed or throttled.
4. Open the discharge gate valve slowly as soon as pump is running.
5. Check the packing glands and see that water seals are properly functioning.
6. Check the running current and investigate any abnormal current demands.

There are a number of causes of centrifugal-pump trouble which it would be well to know about. These are listed in Table 3.5. A list of ten symptoms, keyed to the possible causes in Table 3.5, is presented in Table 3.6.

Figure 3.3 is useful in determining quickly the cost of power used in pumping, if one knows the overall efficiency of the pump and motor, the unit cost of electricity in cents per kilowatt hour, and the pumping head. For instance, if the cost of current is 1 cent per kilowatt-hour and the overall efficiency is 75 per cent, the cost of pumping 1 mil gal of water 1 ft high is 4.2 cents. Pumping 1 mil gal 200 ft high, therefore, costs \$2.00 × 4.2 cents, or \$8.40.

Controls

The starting, stopping, and regulation of pumping equipment can be achieved manually, automatically, or semiautomatically. As a result of the ever increasing cost of labor and the desire constantly to improve service, the principles of automation are more and more being applied to various

TABLE 3.6

Checklist of Centrifugal-Pump Troubles and Possible Causes

Trouble	Possible Causes (Table 3.5)
1. Pump does not deliver water	1–4, 6, 11, 14, 16, 17, 22, 23
2. Insufficient capacity delivered	2–11, 14, 17, 20, 22, 23, 29–31
3. Insufficient pressure developed	5, 14, 16, 17, 20, 22, 29–31
4. Pump loses prime after starting	2, 3, 5–8, 11–13
5. Pumps requires too much power	15–20, 23, 24, 26, 27, 29, 33, 34, 37
6. Stuffing box leaks excessively	13, 24, 26, 32–36, 38–40
7. Packing has short life	12, 13, 24, 26, 28, 32–40
8. Pump vibrates or is noisy	2–4, 9–11, 21, 23–28, 30, 35, 36, 41–47
9. Bearings have short life	24, 26–28, 35, 36, 41–47
10. Pump overheats and seizes	1, 4, 21, 22, 24, 27, 28, 35, 36, 41

phases of water works operation. Within the past few years, the development of sensing, transmission, control, and evaluation elements for automatic control of the pumping operation has been rapid.

It is a relatively simple matter to throw a switch and start a motor-driven pump. It is not much more difficult to arrange automatic or semiautomatic operation from sensing equipment near at hand or from remote points. The factor sensed may be water elevation, water pressure, the quantity of water pumped, or a combination of the three. It is possible to operate and control the entire pumping function in complex distribution systems from a single point or multiple points. Long-distance or remote sensing operations may be performed electrically through leased telephone circuits, by radio, or by pressure communicated through the water in the pipelines. Each control function must be analyzed, planned, and accomplished individually.

QUESTIONS

1. What is the difference between low-lift and high-lift pumping?
2. How do mixed-flow and axial-flow pumps differ from the true centrifugal pump?
3. Operation of two or more centrifugal pumps in parallel produces an increase in capacity. Is this statement true or false? Why?
4. What purpose does an overload relay serve on a starter used with an electric motor?
5. What is the difference between conditions under which suction lift and suction head exist?

Correction

Chapter 2 of AWWA Manual M8, "A Training Course in Water Distribution" (April 1961 JOURNAL, Vol. 53, pp. 458–484), contained an incorrect statement. On p. 481, in line 4 of the section entitled "Hydraulics of Leaks," the phrase "*C* is the Hazen-Williams coefficient" should read "*C* is the coefficient of discharge."

The error will be corrected in the reprint of the manual.


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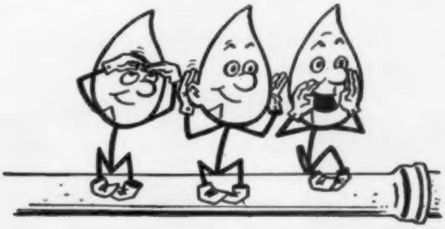

Percolation and Runoff

Prepostconferencewise we can report that Detroit on Jun. 4–9 played host to a *tre*mendous crowd of water workers that virtually inundated Cobo Hall. Being in a hurry now and a little more than a month before the fact, we'll save the details until next issue and merely note with unremarkable prescience that the following officers and directors assumed their duties on the last day of the Conference:

President—John W. Cramer, senior partner, Fulton & Cramer, Lincoln, Neb. Born in North Platte, Neb., in 1914, he received a B.S. in civil engineering from the University of Nebraska in 1940. From 1940 to 1945 he had engineering assignments with several companies in California and Nebraska. He became a partner of Fulton & Cramer in 1945 and senior partner in 1959. He is a registered professional engineer in five states.

A member of the Association since 1948, he has served the Nebraska Section as secretary (1948–51) and AWWA director (1951–53). He was the section's choice to receive the Fuller Award in 1954. He has been active in the Water Resources Division, as trustee (1954–56), secretary-treasurer (1956–57), vice-chairman (1957–58), and chairman (1958–59). He has also been a member of the Committee on Highway Relocation Costs. He was AWWA vice-president in 1960–61.

Other professional affiliations include ASCE, ASME, National Society of Professional Engineers, and Nebraska Engineering Society (past-president).

Vice-President—William D. Hurst, city engineer, Winnipeg, Man. Born in Winnipeg in 1908, he received his B.S. in civil engineering in 1930 from the University of Manitoba. Post-graduate work was done at Virginia Polytechnic Institute. He became a resident and office engineer of the Winnipeg Water Works Department in 1931, engineer of water works in 1934, and deputy city engineer in 1944. From 1949 to 1960 he was chairman of the commissioners of the Greater Winnipeg Water and Sanitary Districts, two municipal boards which were replaced on Jan. 1, 1961, by the Metropolitan Corporation of Greater Winnipeg.

A member of AWWA since 1934, he received the Fuller Award in 1946. He served as chairman of the former Minnesota Section in 1947–48, chairman of the Canadian Section in 1952–53, and was director from the Canadian

(*Continued on page 38 P&R*)

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V.P.—Hurst

Treas.—Orchard

Section in 1952–55. In addition he has served on several Association committees.

Other organizations to which he belongs include the Canadian Institute on Sewage and Sanitation, the Engineering Institute of Canada, the Manitoba Association of Architects, and the Manitoba Association of Professional Engineers (president, 1950–51). He is former president (1958–59) of the American Public Works Association and a diplomate of the American Academy of Sanitary Engineers.

Treasurer—William J. Orchard, consultant, Wallace & Tiernan Inc., Belleville, N.J. Born in Boston, Mass., in 1888, he was graduated from Massachusetts Institute of Technology in 1911 with a degree in sanitary engineering. He served with the Massachusetts Board of Health and the Metropolitan Water Commission, and also held the post of assistant sanitary engineer with the New Jersey Health Dept. In 1915 he entered the employ of the Wallace & Tiernan organization. During World War I he originated and developed mobile water purification equipment for the US Army. He rose to the position of general manager of Wallace & Tiernan, retiring in 1954 but continuing as consultant to the company.

An Honorary Member of AWWA (joined in 1917), he received the Diven Medal in 1954 and the Jordan Achievement Award in 1956. A director for many years, he has served as chairman of the Convention Management Committee and as a member of the Executive Committee and the General Policy Committee. He was chairman of the Finance Committee from 1951 to 1957, when he was elected treasurer. Other organizations to which he belongs include WSWMA (past president), NEWWA, WPCF, and APHA.

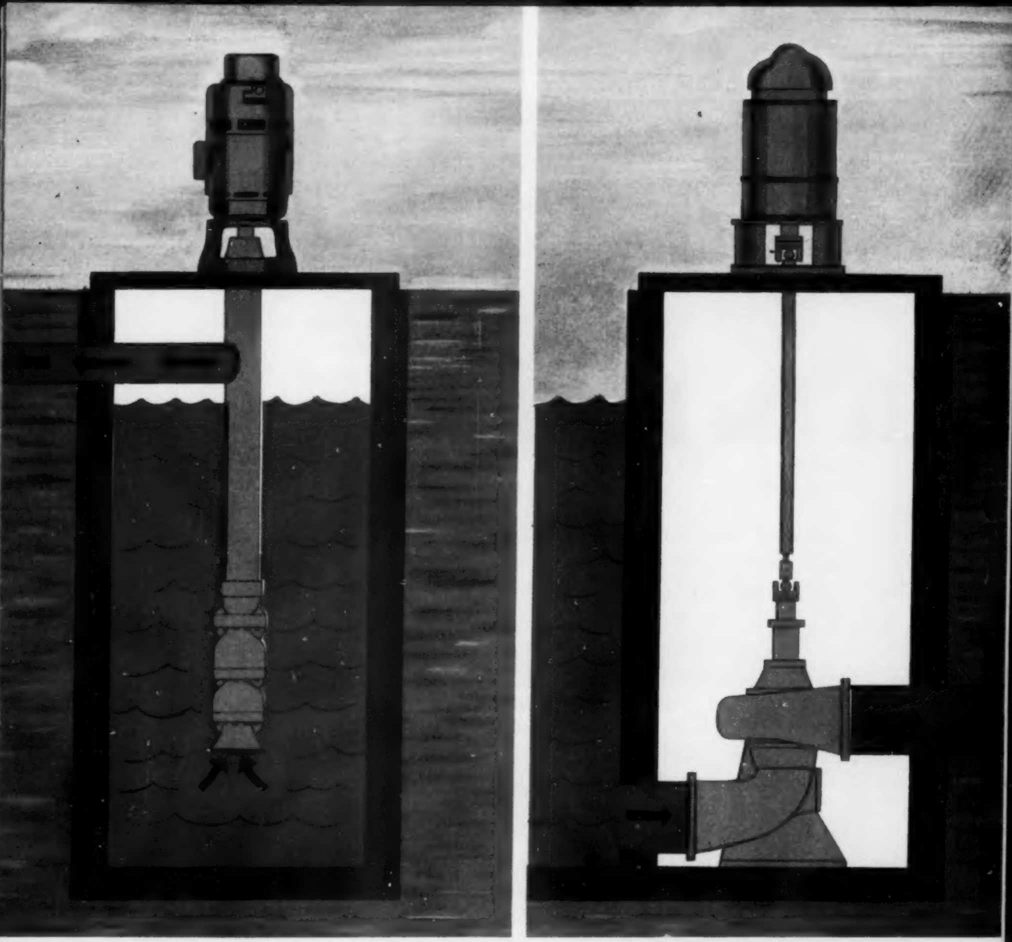
SECTION DIRECTORS

Canadian—Henry P. Stockwell Jr., commissioner of water works, Ottawa, Ont. Born in Stanstead, Que., in 1904, he received his B.S. in chemical engineering from McGill University in 1924, after which he spent eight years in research and technical work for the pulp and paper industry. In 1932 he joined the Ottawa water department as a chemical engineer. He became assistant water works engineer in 1944, deputy commissioner in 1950, and assumed his present post in 1958.

A member of AWWA since 1933, he served as chairman of the Canadian Section in 1957–58. He is also a member of the Engineering Institute of Canada and the Association of Professional Engineers of Ontario.

Indiana—Leo Louis, president and general manager, Gary-Hobart Water Corp., Gary, Ind. and president, Long Island Water Corp., Lynbrook, N.Y. Born in Piqua, Ohio, in 1915, he graduated from Purdue University in 1936.

(Continued on page 40 P&R)



(*Continued from page 38 P&R*)

Canadian—Stockwell

Indiana—Louis

After serving with the Indiana Board of Health from 1939 to 1947, he became city engineer of Piqua, Ohio, and in 1949, superintendent of the Cedar Rapids (Iowa) Water Department, a position he held until 1954, when he became vice-president and manager of the Gary-Hobart Water Corp. He was selected as president of it and the Long Island utility in 1960.

A member of AWWA since 1941, he served the Iowa Section as vice-chairman (1953–54) and the Indiana Section as vice-chairman (1957–58) and chairman (1958–59). He has served on many of the Association's committees and received the Fuller Award in 1947. He is a member of ASCE and the National Society of Professional Engineers. He is a registered professional engineer in Indiana, Ohio, and Iowa.

Iowa—Mark E. Driftmier, superintendent, Burlington (Iowa) Municipal Water Works. Born in Clarinda, Iowa, in 1905, he received his degree from Iowa State University in 1928, after which he began as assistant superintendent for the former Citizen's Water Co. of Burlington. He was appointed superintendent in 1941, two years before the city acquired the utility and it became a municipal department. Recently, he was appointed superintendent of the city's sewage treatment plant as well.

A member of AWWA since 1937, he served as vice-chairman of the Iowa Section in 1950 and its chairman in 1951. In 1956 he was nominated to receive the Fuller Award. He has also served on various section committees. He is a member of the Iowa Engineering Society and the state's Sewage and Industrial Wastes Assn.

Kansas—G. Dorr Pelton, superintendent of the Topeka, Kan., water department. Born in Montgomery, Iowa, in 1905, he received his B.S. from Washburn University in 1927. He joined the Topeka water department in 1926 as a draftsman, became distribution engineer in 1932 and departmental engineer in 1943. In 1950 he assumed his present position.

A member of AWWA since 1938, he served the Kansas Section as its vice-chairman in 1954 and chairman in 1955. He is a member of the National Society of Professional Engineers, the Kansas Engineering Society and the Topeka Engineers Club, of which he was secretary in 1942–45 and president in 1947.

Iowa—Driftmeier

Kan.—Pelton

(*Continued on page 42 P&R*)

(*Continued from page 40 P&R*)

Mo.—Lischer

N.C.—Harris

Missouri—Vance C. Lischer, partner, Horner & Shifrin, St. Louis, Mo. Born in Beardstown, Ill., in 1906, he received his B.S. in civil engineering from Washington University, St. Louis. He joined the St. Louis County Water Co. as an engineer in 1928 and became engineer in charge of production in 1931. In 1944 he joined Horner & Shifrin as a principal engineer, became an associate partner in 1945, and a full partner in 1955.

A member of AWWA since 1935, he was chairman of the Missouri Section in 1955 and is currently vice-chairman of the Association's Standardization Committee. He was awarded the Goodell Prize in 1938 and received the Fuller Award in 1952. Other professional affiliations include ASCE, ASME, American Sanitary Engineering Intersociety Board, and the American Institute of Consulting Engineers.

North Carolina—Stanford E. Harris, superintendent, water and sewerage division, Winston-Salem (N.C.) Dept. of Public Works. Born in Lenoir, N.C., in 1919, he studied at Davidson College and the University of North Carolina. From 1941 to 1948, he was city engineer at Lenoir, N.C. In 1948–49, he was superintendent of the Goldsboro (N.C.) water and sewerage department. In 1949 he assumed his present position at Winston-Salem.

A member of AWWA since 1941, he was vice-chairman of the North Carolina Section in 1953–54 and section chairman in 1954–55. In 1959 he received the Fuller Award. He is a past-president of the North Carolina Water Pollution Control Assn. and a past-president of the state's Water Works Operators Assn.

Rocky Mountain—William F. Turney, consulting engineer, Santa Fe, N.M. Born in Mesilla, N.M., in 1914, he received his degree of bachelor of science in civil engineering from New Mexico State University in 1938, following which he began working on a series of projects for the government. He was superintendent of a project for the W.P.A. in 1938–39, draftsman for the International Boundary Commission in 1939–40, and an engineer for the US Grazing Service in 1940–41. In 1941 he joined the US Army as a first lieutenant in the infantry and left the service in 1945 as a lieutenant colonel in the Corps of Engineers, after serving on many wartime construction projects. In 1946 he organized his firm, W. F. Turney & Associates.

Rocky Mountain—Turney

South Dakota—Campbell

(*Continued on page 44 P&R*)

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A member of AWWA since 1954 (Corporate representative in 1954–60), he served as vice-chairman of the Rocky Mountain Section in 1957 and chairman in 1958. He is a member of ASCE, the National Society of Professional Engineers, and the Society of American Military Engineers. He is a diplomate of the American Academy of Sanitary Engineers and a registered professional engineer in New Mexico, Colorado, Wyoming, and Arizona.

South Dakota—W. B. Campbell, president, Campbell's Inc., Flandreau, S.D. Born in Athens, Ohio, in 1893,

Southeastern—Kauffman

Virginia—Johnson

he has been actively engaged in sales of water utility products since 1919. In 1925, he was employed as sales engineer for A. P. Smith Mfg. Co. In recent years he founded Campbells Inc., which represents several manufacturing firms in a five-state area. He has been a member of AWWA since 1943.

Southeastern—Robert C. Kauffman, partner, Wiedeman & Singleton Engineers, Inc., Atlanta, Ga. Born in Atlanta in 1907, he attended Loyola University and Georgia Institute of Technology, after which he joined the firm of Lockwood, Green & Co., Spartanburg, S.C., as a civil engineer. Following service with the US Army Corps of Engineers, he joined Wiedeman & Singleton in 1935 and became a partner in 1959.

A member of AWWA since 1950, he was chairman of the Southeastern Section in 1958 and received the Fuller Award in 1956. He is a member of ASCE and has been active in the Georgia Water & Waste Assn. In 1959 the Atlanta water department presented him with its award for Engineer of the Year. He is a registered professional engineer in Georgia and South Carolina.

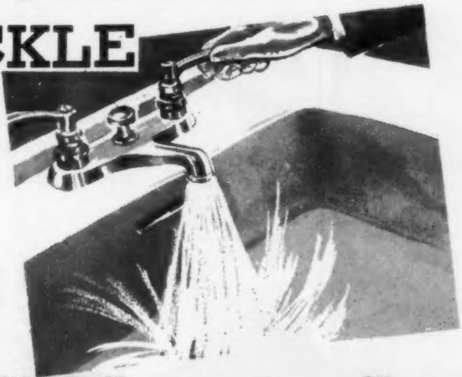
Virginia—Harold A. Johnson, superintendent of water purification at Danville, Va. Born in Atwater, Ohio, in 1905, he received his degree from the University of North Carolina in 1927. He was superintendent of purification at Oxford, N.C., in 1927–29, when he assumed his present position at Danville.

A member of AWWA since 1928, he is a charter member of the Virginia Section, as well as a Life Member of the Association. He was vice-chairman of the Virginia Section in 1937–38 and chairman in 1938–39. In 1953 he was the section's recipient of the Fuller Award. Other professional affiliations include APHA.

West Virginia—Cecil C. MacDonald, president, West Virginia Water Co., Charleston, W.Va. Born in East Rochester, Ohio, in 1898, he attended the University of Pittsburgh. In 1927 he received his certificate as a CPA from the state of Pennsylvania. In 1928 he joined the Federal Water Service Corp., New York City, becom-

(Continued on page 48 P&R)

NOT JUST A TRICKLE



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(Continued from page 44 P&R)

ing assistant secretary and assistant treasurer of its midwest division in 1929 and secretary in 1932. In 1945 he joined the West Virginia Water Service Co., predecessor of his present firm, as vice-president and treasurer. He became president in 1957. A member of AWWA since 1929, he is a Life Member.

Wisconsin—Thomas M. McGuire, superintendent, Water and Light Dept., Menasha, Wis. Born in Des Moines, Iowa, in 1901, he received his B.S. in electrical engineering from Iowa State College in 1926. Following several years as an electrical engineer for Milwaukee firms and as a private contractor, he became manager in 1938 of the Plymouth (Wis.) Electric and Water Dept., remaining there until 1956, when he took his present position at Menasha.

A member of AWWA since 1939, he served as vice-chairman of the Wisconsin Section in 1949 and as section chairman in 1950. He is a member of the National Society of Professional Engineers and a past-president of the Wisconsin Municipal Utilities Assn.

Manufacturer—George W. Kelsey, senior vice-president, B-I-F Industries, Inc., Providence, R.I. Born in 1898 in New York City, he received his degree

W.Va.—MacDonald

Wis.—McGuire

Mfrer.—Kelsey

in mechanical engineering from Stevens Institute of Technology in 1921. In 1922–27 he was industrial engineer at the Bayonne (N.J.) refinery of Tidewater Oil Co., and in 1927–31, he was associate professor in the extension division of Rutgers University. In 1932 he founded the consultant firm of G. W. Kelsey & Co. He joined B-I-F Industries (then Builders Iron Foundry) in 1938 as industrial sales manager, becoming a director in 1944 and vice-president in 1947.

The representative of B-I-F in AWWA, he is also a member of WPCF and ASME and was president in 1960 of WSWMA.

'Hydronauts of the New Frontier' were those upon whom Senator Robert S. Kerr called at the National Watershed Congress in April to solve our water problems. And, lest the appellation he used evoke an image of Harvard crews racing across your reservoir, we hasten to assure that what the Senator really had in mind were "hydromasters" or, perhaps, "hydrowizards" who could "crack the barriers of stream pollution and desalinization," thereby, as President Kennedy has suggested, dwarfing even present achievements in the conquest of space. Indications are that the program of the "New Frontier" will place increasing

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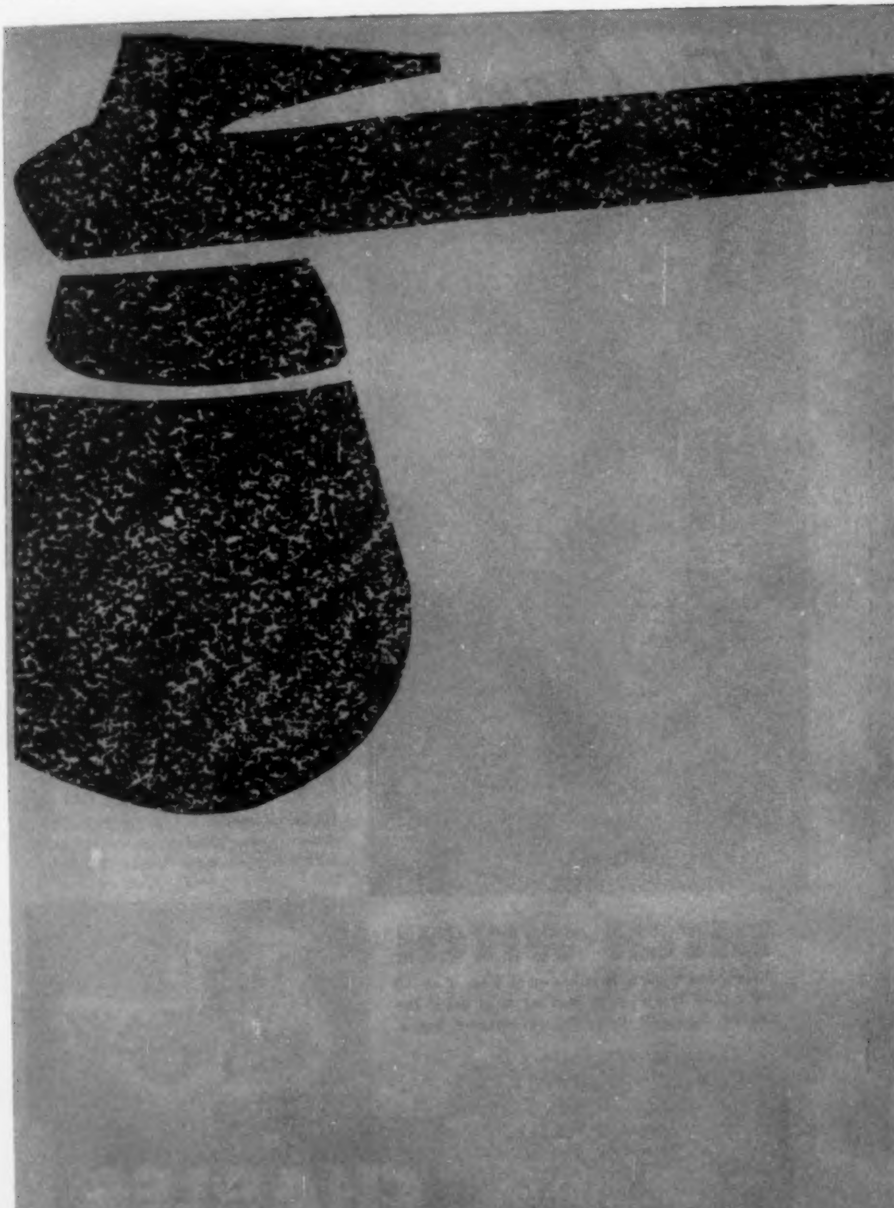
emphasis on "cracking" these barriers, and even though we might be inclined to quarrel a bit with the priorities involved, it behooves us to recognize a millennium when we see one—and to make the most of it.

What prompts us to call this a millennium are not such signs as the provision in the depressed-areas bill that makes available $300,000,000 in federal loans for, among other things, modernizing water systems, but, rather, the overall impact of this aspect of "New Frontiersmanship" on public appreciation of the importance of water supply. It remains for the water supply industry and individual water utilities to capitalize on this interest in developing support for the specific projects required to solve specific problems, but, as far as public awareness is concerned, it must be recognized that we've never had it so good. As a matter of fact, we will undoubtedly deserve it if we make hydronaught of the New Frontier.

Nematodes—our public enemy No. 1 of 1960—have just been found to have a fatal sweet tooth. Finder was plant pathologist W. A. Feder of the US Dept. of Agriculture horticultural field laboratory at Orlando, Fla., who discovered that he could not only kill, but actually disintegrate, nematodes with ordinary sugar, the lethal action being effected by dehydration. As a matter of fact, the procedure was found so effective that, in some of the tests, scientists could not find a trace of the worms—even with a microscope—24 hr after they had been doused with sugar water.

We have heard nothing of experiments on waterborne nematodes, but victory could be sweet.

(Continued on page 96 P&R)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Key: In the reference to the publication in which the abstracted article appears, 39:473 (May '47) indicates volume 39, page 473, issue dated May 1947. If the publication is paged by the issue, 39:5:1 (May '47) indicates volume 39, number 5, page 1, issue dated May 1947. Abbreviations following an abstract indicate that it was taken, by permission, from one of the following periodicals: *BH—Bulletin of Hygiene (Great Britain); CA—Chemical Abstracts; Corr.—Corrosion; IM—Institute of Metals (Great Britain); NSA—Nuclear Science Abstracts; PHEA—Public Health Engineering Abstracts; SIW—Sewage and Industrial Wastes; WPA—Water Pollution Abstracts (Great Britain).*

RADIOACTIVITY

Radioactive Substances in Relation to Water Supply. H. Schopper. *Deut. Gewasserkundl. Mitt.* (Ger.), 3:63 ('59). The aim of the author is to explain to the water industry the new problems arising from the peaceful uses of atomic energy. He deals with the structure of the atom, natural radioactivity, nuclear reactions, and artificial radioactivity. Methods and app. for detection and measurement of radioactivity, methods of decontamn. of polluted water, and the uses of radioactive isotopes in the water supply industry are described.—*WPA*

Content of Thorium and Other Radioelements in Natural Waters. V. V. Cherdyntsev & U. K. Asylbaev. *Izvest. Vysshikh Ucheb. Zavedenii, Geol. i Razvedka* (Moscow), No. 9, 125 ('58). This is a study in which measurements of radioactive isotopes of natural waters were made for isotopes of U (UI, UII), Th (UX_1, Io, RdAc, Th, RdTh), Ac, and Ra. Data are presented in tables for cont. of radioactive elements in natural waters of the following 3 regions: (1) rare-metal mineralization of the hydrothermal phase, (2) pegmatite mineralization contg. light metals, and (3) pneumatolytic mineralization contg. minerals of rare elements and also minerals with elevated radioactivity. Results showed that avg values of Ac/Ra and UX_1/Ra vary for different regions, and can probably serve as hydrogeochem. criteria.—*CA*

Radioactive Water Poses New Problems. C. T. Dickert; R. Hetherington; & C. F. Raines. *Power,* 102:88 ('58). Conditions to which water is exposed inside a pressurized water reactor make it necessary to use water with a high degree of purity. Reasons for this are discussed. The effects of irradiation and the presence of oxygen in the water cause corrosion and corrosive deposits, and this is aggravated by the presence of fission products.—*WPA*

Concentration of Radioelements From Large Volumes of Natural Water. K. F. Lazarev & S. M. Grashchenko. *Radiokhimiya* (Moscow), 1:493 ('59). To reduce the settling time of $Fe(OH)_3$ and $BaSO_4$, the co-pptg. carriers of very dild. radioelements in natural waters, it is recommended that coagulating ions of opposite charge be added to the colloidal ppts.—for example, paper pulp, glass powder, finely dispersed ion-exchange resin, and the like. In order to conc. Ra isotopes in a H_2O sample by $BaSO_4$ pptn., it is recommended that HNO_3 soln. be used at pH = 1. A typical procedure is as follows: to a 150–200 liter sample is added 2 g Fe(III), 1 g Ba(II) (with some H_2SO_4, in case of river water), and NH_3, until $Fe(OH)_3$ is formed. To the sample 6–8 g starch is then added, and the $Fe(OH)_3$–$BaSO_4$ ppt. is settled for 3 hr. The ppt. is dried and ignited, to burn the starch, and then washed with HCl, forming a fairly pure $BaSO_4$ with co-pptd. Ra isotopes.—*CA*

Radioactivity of Domestic Water Supplies. M. A. Blanc. *Compt. Rend. Acad. Agr. France,* 45:450 ('59). Two water supplies in Berne were found to possess radioactivity in excess of the allowable amt. for potable waters. The radioactivity appeared to be of natural origin—that is, from the igneous rocks of the area from which the water came. —*PHEA*

Measurement of Radioactivity in Water. J. Ralkova. *Jaderna energie* (Prague), 6:89 ('60). Some methods of detg. very low activity in natural waters are reviewed. Methods of measuring α, β, and γ activity are described, including recent instruments for detg. low activities, such as a coaxial counter and a gas-filled scintillation detector.

(*Continued on page 64 P&R*)

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(Continued from page 62 P&R)

No sufficiently rapid, reliable, and sensitive method for field use is known as yet.—*CA*

Determination of Strontium-90 in Water Samples With an Ion-Exchange Procedure. H. KNAPSTEIN. *Z. anal. Chem.* (Ger.), 175:255 ('60). A method for the detn. of Sr^{90} in surface, cistern, and drinking H_2O, based on the adsorption of all cations on Dowex 50 cation-exchange resin and selective elution of the alk. earth ions by NH_4 lactate soln., is described. All aspects of the problem are reviewed.—*CA*

Experiments on the Decontamination of Water With Reference to the Preparation of Potable Water From Radioactively Contaminated Surface Water. E. H. GRAUL & E. K. REINHARDT. *Atompraxis* (Ger.), 4:397 ('58); 5:5 ('59). A 4-stage purifier having a capacity of 1 l/hr and consisting of a column packed with metal fibers, a sheet filter with a Seitz pad, a column packed with activated C, and a column packed with a mixed-bed ion exchanger was tested with H_2O contg. 250 μc/l of Sr^{90} and 100 μc/l of P^{32}. The activity of the product was $1\text{–}2 \times 10^{-6}$ μc/l. A 5-stage purifier (separate cation and anion exchangers instead of the mixed-bed exchanger) was successfully tested with 1 μc of mixed fission products per liter of H_2O. Large-scale portable filter units working on the same principles are being developed.—*CA*

Adsorption of Radioactive Elements During Conduction of Radon Containing Water Through Pipes. G. V. YAKIMOV. *Nauch.-Doklady Vysshei Shkoly, Stroitel'stvo* (USSR), No. 2, 297 ('58). Expts. were conducted on the active deposits of RaA, RaB, and RaC obtained when H_2O of high radon concn. was transported from a 330-liter reservoir through 110 m of a steel pipe of 25 mm, having an avg incline of 0.06. Two probes were taken from the cylinder and from the end of the conduit. It is shown that the ratio RaA:RaB:RaC is 1:6.08:4.78 in the reservoir, and 1:3.47:6.75 in the conduit, and that only a fraction of these products is adsorbed in the conduit, so that a sufficient no. of short-lived isotopes can be transmitted through pipe.—*CA*

Concentration of Radioactivity and Detection of Cobalt-60 and Zinc-65 in Rainout. H. L. KRIEGER; J. E. GILCHRIST; & S. GOLD. *Talanta*, 6:254 ('60). Ion-exchange resins have been used to conc., isolate, and det. low levels of radioactive contaminants in rain water. After the particulate and associated activities are removed by filtration, the ionic materials are retained on cation- and anion-exchange resin columns which are arranged in series. This technique lends itself to the concn. of the low-level activities, because the filtered rain water contains a negligible amt. of solids. Consequently, a large volume can be passed through the resin columns before the exchange capacity is approached. Gamma scintillometry was used to identify the γ emitters in each of the components in this concn. study. In addition to the expected fission product activities in rainout, photopeaks attributed to Co^{60} and Zn^{65} were discernible. Despite the fact that the activity levels of these nuclides were very low, their photopeaks were considered to be significant. But for positive identification, quantitative sepn. was required. A sequential elution scheme based on the anionic adsorption of cobalt and zinc in solns. containing HCl in high concn. was used to separate the cobalt from the zinc, and from other anions adsorbed on the Dowex-1-(Cl) resin. Following elution, each nuclide was radiochemically isolated for quantitative measurement. —*PHEA*

Decontaminating Radioactive Ocean Areas Through Flocculation. M. HONNA & A. E. GREENDALE. *Ind. & Eng. Chem.*, 51:697 ('59). The removal of radioactivity from natural sea water was studied as a preliminary step in detg. the feasibility of decontamg. ocean areas. The test method was removal by a settling floc. After preliminary tests in hydrometer cylinders, the more promising materials were tested in 8.5×120-cm columns using 6 liters of natural sea water contamd. with single nuclides or with mixed fission product; 0.55 g of floc material was added. The best decontaminant was sodium silicate, which removed up to 35% of the activity. Results of multiple additions of silicate indicated that removals up to 80% could be expected. Removal of Sr was poor, probably because of the presence of inactive Sr carrier element. Further information is needed on solution rate of floc, desorption rate of activity from the floc, settling rate, rate of transport of floc in the sea, and effect of depth.—*PHEA*

(Continued on page 66 P&R)

(*Continued from page 64 P&R*)

Fixation of Radioactive Wastes by Fusion With Silicates. J. BERANEK; K. LUSTIG; & J. SAIDL. *Jaderna energie* (Czech.), 5:261 ('59). Among the methods of fixation of high-activity liquid radioactive wastes from the chem. processing of spent fuel elements, that of incorporation in glass is favored. Raw materials for the glass have to be chosen to produce high resistance toward chemicals, esp. water, but also a low melting temp., to avoid volatilization of Ru^{106} and Cs^{137} during prepn. A search for a compromise material to satisfy both conditions led to the use of znelec, an igneous rock, which is used in Czechoslovak glass technology. The acid radioactive soln. is mixed with the finely ground rock to give silica gel from which H_2O and HNO_3 are easily evapd. The melting process is speeded up by using 3 furnaces, the 1st for drying and preheating to 800°C, the 2nd for melting at 1350°C, the 3rd for cooling to 800°C. In spite of its low soly., the glass should be stored away from ground water, and in such a way that the heat from radioactive decay does not melt it. The storage space required and the cost are discussed.—*CA*

Inactivating Radioactive Waste Waters by Evaporation. S. KRAWCZYNSKI. *Kerntechnik,* 1: No. 5, 145 ('59). The evapn. method is compared to other procedures such as crystn. *in vacuo,* chem. pptn. ion exchange, electrodialysis, liquidus-liquidus extn., electrolytic plating, and biologic sepn. The redn. in process efficiency is described when volatile or gaseous radioactive constituents are present, such as radioactive I, RuO_4, Ar, Xe, Kr, or Nt.—*CA*

Evaluation of the Ground Water Sources From Territories Polluted With Radioactive Products From Uranium Fission. A. S. BELITSKII. *Gigiena i Sanit.* (Moscow), 23:10, 23 ('58). The study reviews the danger of radioactive fission products passing from the surface of the ground to subterranean H_2O sources. The danger is not very great.—*CA*

(*Continued on page 68 P&R*)

(Continued from page 66 P&R)

Study of the Solidification of Radioactive Wastes. R. Bonniuad & P. Cohen. *Energie Nucleaire* (Fr.), 2:22 ('60). Various methods are considered for the solidification of radioactive wastes. The methods indicated are: (1) firing; (2) plastic coating of the wastes; (3) gelification and hardening by organic binders; and (4) cementation which seems to be the least expensive (9 francs worth of raw materials per kilogram of waste) and the most simply effected process for solidifying radioactive wastes of the type studied. The loss of activity by immersion in water is slow and quickly reaches a plateau. Introduction of sodium silicate into the composition of the cements results in reduced leaching by water; a sprayed coating of sodium silicate would reduce it still further. The best composition studied was portland cement without sand. The cost of the operation of a continuous industrial installation remains to be studied (equipment, labor, and curing area). It should be noted that the use of the cementation method results in an increase in volume of the waste to be stored by 35%. The estimate of costs must take into account the fact that the 200-liter barrel used could be replaced by a lighter container, or perhaps be eliminated altogether.—*PHEA*

Averages and Results of a Study of Radioactivity Due to Radon in Natural Waters. G. Jurain. *Geochim. et Cosmochim. Acta* (Fr.), 20:51 ('60). Data obtained in field surveys in France (Vosges, Vendee, and Brittany) during 1958 and 1959 have been analyzed statistically. Rn is distributed log normally in a given geol. formation. The Rn cont. of waters are very often greater than that found in biol. systems and above safe tolerance dosages. The anal. and statistical data are included. The method, which is described in detail, is fast (20–30 detns. daily) and relatively inexpensive. Rn cont. of the order of 10^{-10} c/l are readily detected. Glass counting tubes with inner walls coated with Ag-activated ZnS are prepd. These are couped optically with the detector for α scintillation counting. A reducing scaler

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(Continued from page 68 P&R)

completes the app., all of which is mounted in a motor vehicle for convenient field use. The method is applicable to monitoring natural waters for safe Rn and Ra levels. It can also serve as a technique for geochem. U prospecting.—*CA*

Radioactivity Measurements of Mineral Waters of the People's Republic of Romania. V. The Radioactivity of the Thermal Waters of the Region of Oradea and Hunedoara (Transylvania). A. Szabo & A. Soos. *Chem. Zentr.* (Ger.), 129:1240 ('58). The investigation of the artesian well of Baile Victoria (formerly Felix), with a water temp. of 48.5°C, showed that its Rn cont. of 0.40 mμc/l has not changed since 1926. The Ra cont. of the water and the slurry is low: 3.71×10^{-13} g/l Ra or 0.45×10^{-12} g/g Ra of the slurry dried at 100°C. In the Baile 1. Maiu (formerly Baile Episcopeii) not far from Baile Victoria, similar values were found. However, the radioactivity of the springs of Geoagiu (region of Hunedoara) reached values up to 3.22 mμc/Rn, 8.21×10^{-13} g/l Ra, and 3.1×10^{-12} g/g Ra of the slurry, dried at 100°C. These springs can, therefore, be considered to be therapeutically important. —*CA*

Fallout Cesium in Surface Sea Water Off the California Coast (1959–60) by Gamma Ray Measurements. T. R. Folsom; G. J. Mohanrao; & P. Winchell. *Nature,* 187:480 ('60). Anals. were made of Ce^{137} in sea water, which ranged from 45 to 163 μμc/kl for an avg of 97 μμc/kl. These values are compared with data, obtained by Yamagata, for Japanese waters of 240–650 μμc/kl. The authors propose that because of the simplicity of detg. gamma activity of the Ce^{137} by gamma spectroscopy that Ce^{137} could be used as a tracer substance for following the movement of fallout in sea water. However, because of the variety in levels observed they caution against drawing conclusions of a general nature from just a few specific samples taken from a given area.—*PHEA*

Investigation of the Contaminants of the Water-Cooling Circuit of the First Soviet Atomic Power Station. P. N. Slyusarev; V. A. Ivanov; & L. N. Nesterova. *At. Energ.,* 6:639 ('59). In studying the corrosion mechanism of stainless steel in contact with the coolant water of the primary circuit of APS-1, it was found that the corrosion rate is proportional to the purge rate of the water and to the reactor power. This is attributed to the oxidation of N from the air dissolved in the feedwater, followed by attack of the piping by the HNO_3 thus formed. This is supported by the fact that the pH of the coolant is lowered, but it remains unchanged in a similar out-of-pile loop, and that the actually detd. pH is higher than that calcd. on the basis of the NO_3^- ions in the soln., as part of the acid is neutralized by the corrosion reaction. By using radiochem., analytic, electrodialysis, and ultrafiltration methods, it was established that Na, Ca, Mn, Ni, Cr, and Co were present as ions, and Cu and Fe were in colloidal state, in contradiction of previous assumption of water chemists. It is recommended to use deaerated water and to change the design of the surge tank, so as to make contact with air impossible.—*CA*

Radioactivity of Domestic Water Supplies. M. A. Blanc. *Compt. rend. acad. agr. France,* 45:450 ('59). Two water supplies in Berne were found to possess radioactivity in excess of the allowable amts. for potable waters. The radioactivity appeared to be of natural origin—that is, from the igneous rocks of the area from which the water came.—*CA*

Removal of Radioactive Iodine From Hospital Waste Waters. T. A. Berezina & V. Y. Golikov. *Gigiena i Sanit.* (Moscow), 25:12 ('60). Up to 97% of the radioactive I present in hospital sewage can be removed by addn. of 5 mg/l stable KI, chlorination, and adsorption of I on EDE-10 resin.—*CA*

Physical and Chemical Properties of Nuclear Power Reactor Waste Solutions. W. J. Lacy; F. M. Empson; & I. R. Higgins. *Ind. Eng. Chem.,* 51:83A ('59). Compns. were tabulated for "standard" waste solns. produced as extn.-column raffinates or as raffinate evaporator products for Purex, TBP-25, STR, Darex, and SIR processes. Phys. and chem. properties were detd. for evapn. of acidic or neutralized waste, neutralization with NaOH or $Ca(OH)_2$, and solids concn. for waste solns.—*CA*

(Continued on page 74 P&R)

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(*Continued from page 72 P&R*)

Disposal of Atomic Wastes in the Earth's Ice Caps. B. PHILBERTH. *Compt. rend.* (Fr.), 248:2090 ('59). The feasibility of disposal of radioactive wastes (produced in the generation of nuclear power) by loading them into bombs and dropping them from the air onto the polar ice caps is discussed. Calcns. intended to demonstrate the safety of such disposal are based on the probable future production of nuclear energy, and the activity and half-lives of the wastes produced in the process. Costs of this disposal also are estimated.—*CA*

Radioactive Mineral Waters in the Romanian People's Republic. A. SZABO. *Acta Chim. Acad. Sci. Hung.*, 18:129 ('59). Ra, Rn, and other radioactive elements were detd. in mineral H_2O, silts, and mofette gases. On the basis of radioactive equil., the H_2O had a low Ra concn. in comparison to the amt. of Rn present. It is possible that Ra was pptd. during the passage of the H_2O through the soil. Part of the Rn was transferred into H_2O by diffusion, without being in contact with Ra-bearing rocks. However, the Ra concn. was high when compared to the U concn. Accumulations of Ra, owing to biol. factors, may exist in the deep layers of the earth's crust. A simple method of extg. Ra from calcareous sediments is described.—*CA*

Fission Product Waste From Reactors—Processing of Highly Active Solutions. T. V. HEALY. *Brit. Chem. Eng.*, 4:538 ('59). A combined program of industrial utilization and disposal of the fission product waste is considered. The problems of long-term storage and disposal can be eased by removal of the long-lived isotopes Cs^{137} and Sr^{90}, which together represent >99.9% of the toxicity of the 20-year-old fission-product soln. Any scheme for sepn. of fission products must begin with a vol. redn. The methods of accomplishing this are presented. This is followed by a description of the methods for the removal of Cs and Sr together or by their individual removal. This, in turn, is followed by the extn. of Ce and Ru. This operation is described. The process combines the sepn. of the 2 long-lived isotopes into small bulk and the remaining short-lived material in large bulk that should be dispensible after 20 years.—*CA*

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(*Continued from page 74 P&R*)

The Distribution of Radioactive Pollutions in a Stagnant Reservoir. A. L. Agre & V. I. Korogodin. *Med. Radiol.,* 5:67 ('60). The distr. of radioactivity in the water, biomass, and bottom deposits of a reservoir is discussed, and the part played by the biomass in removing radioactive substances from the water and transferring them to the bottom deposits is outlined.—*WPA*

Measurement of Artificial Radioactivity in Rainwater at Gulmarg. L. Vir Sud & P. S. Gill. *Bul. inst. politeh. Iasi,* 4:127 ('58). Measurements are reported for samples collected at a height of 9,000 ft during Jun.–Jul. 1956, Jun.–Sep. 1957, and Jan.–Jun. 1958. Samples of 5,000 ml were collected and concd. to approx. 30 ml by boiling. A 2-day period was allowed for the decay of daughter products of Rn^{222} and Rn^{220}. The concd. samples were then counted by placing them in a glass jacket surrounding a thin-walled Geiger tube. Some of the rains showed the presence of activity while others did not. Activity values, corrected for tube efficiency and surface factors of the counter, were in the range of 1,000 6,466 disintegrations/min/l. Tap H_2O was tested on many occasions but failed to show activity.—*CA*

Effects of Decontaminating Agents on the Purification of Residual Radioactive Waters. J. Cantel & P. Cohen. *Comm. energie atomique* (Fr.), No. 761, 138 ('58). A fission product soln. in HNO_3 (pH 1.6) and a reconstituted atomic plant effluent were treated with various decontmg. agents. Detergents generally had no effect or a harmful effect on pptn. of the contaminants. A soap and an abrasive detergent were effective. Some detergents, citric acid, Versene, HF, and NaOCl were effective in decontmg. one soln. but not the other.—*CA*

Control of Radioactive Wastes. A. S. Flemming. *Pub. Health Repts.,* 74:883 ('59). The author reports and discusses the significance of the first enforcement action

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under the 1956 US federal law controlling the contamn. of interstate waterways by radioactive waste waters. In the period Apr. 1958–Apr. 1959, the US Public Health Service carried out a survey of the Animas River in southwestern Colorado and northwestern New Mexico which showed that the water contained 40–160% more radioactivity than the maximum permissible concentration, owing to the discharge of waste waters from uranium-milling operations at the plant of the Vanadium Corp. at Durango, Colo. Following proceedings under the 1956 federal law, the corporation is now required to reduce the radium cont. (both soluble and insoluble) of the waste waters to the minimum it is possible to achieve by known methods, before discharge to the river. Although about 30,000 people use water from the Animas River, the situation was brought under control before the pop. had ingested amts. of radioactive material sufficient to cause detectable damage to health. During the survey of the river, a scarcity of fish and other aquatic fauna was noted and found to be due to a number of toxic chemicals which were also contained in the waste waters from the plant of the Vanadium Corp.; the toxic chemicals will, in the future, be recovered before the waste waters are discharged to the river. During 1960, the US Public Health Service intends to begin studies on the radioactivity in 3 rivers in Wyoming (the Bighorn, Sweetwater, and North Platte rivers).—*WPA*

Orographical and Climatological Influence on Deposition of Nuclear Bomb Debris. P. B. Storebo. *J. Meteorol.*, 16:600 ('59). Deposition of bomb debris from the stratosphere is examd. by available worldwide measurements of long-lived radioactive isotopes. The assumption that Sr^{90} is more rapidly brought down to earth by pptn. than is Cs^{137} is shown to be reasonable and might explain Norwegian, Dutch, and British measurements of the Cs^{137}/Sr^{90} ratio in pptn., provided various climatic factors are taken into account. This interpretation of the Cs^{137}/Sr^{90} ratio together with measured total Sr^{90} deposition is in agreement with accepted latitudinal flow models for low and medium latitudes.—*CA*.

Treatment of Radioactive Effluents at the Mol Laboratories. P. de Jonghe; L. Baetsle; & G. Mosselmans. *Proc. UN Intern. Conf. Peaceful Uses At. Energy, 2nd, Geneva, 1958*, 18:68 ('58). A $Ca_3(PO_4)_2$ pptn. and trickling filter were used to remove radioisotopes from effluent with varying results. Decontm. of more than 95% of the U and 80–95% of the β-γ emitters was achieved. Optimum adsorption properties of brown coal (lignite) were shown for water of very low mineral cont. at pH 3–5 and for tap water at pH 7–9.—*CA*

Radiochemical Determination of Radium-C and Thorium-C in Radioactive Springs. I. Hataye. *Mem. Fac. Sci., Kyushu Univ., Ser. C* (Japan), 3:63 ('58). The method was designed for the determn. of radium-C (Bi^{214}) (I) and thorium-C (Bi^{212}) (II) in radon-containing carbonated mineral springs; I and II were extracted by *iso*amyl alcohol as BiI_4^-, on the addition of KI in acid soln. The respective activities of extracted I and II were measured by a Lauritsen-type electroscope; II was used as a tracer in the detmn. of I.—*PHEA*

HYDROLOGY, CONSERVATION, AND IRRIGATION

Acrolein for the Control of Water Weeds and Disease-Carrying Water Snails. J. van Overbeek; W. J. Hughes; & R. Blondeau. *Science*, 129:335 ('59). Injection of the biocide acrolein into irrigation canals killed submersed weeds, thereby reducing flow resistance and increasing capacity. In a 20-mi canal, 150 gal raised throughput from 311 to 552 cfs. Acrolein also effectively eradicated aquatic snails; it promises to become a useful tool in the battle against *Schistosoma* blood flukes.—*PHEA*

Influence of Monolayers on Evaporation From Water Storages. I. Potential Performance of Monolayers of Cetyl Alcohol. W. W. Mansfield. *Aust. J. Appl. Sci.*, 9:245 ('58). Calculations show that, in Australian climates, permanent and complete application of a monomol. film of cetyl alcohol to the surface of stored water should reduce the rate of natural evaporation by 50–80%. The influence of atm. conditions on evaporation is discussed.—*PHEA*

A Brief Characteristic of Hydrological Conditions and of the Microscopic Aquatic

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Population of Galichskoe Lake. N. V. Korde & S. N. Ulomskii. *Trudy Lab. Sapropel. Atlozhenii* (Moscow), No. 7, 68 ('59). According to physicochem. studies (color, depth, temp., pH, O and CO_2 cont., and mineralization) Galichskoe Lake is a hydrocarbonate-calcareous, sweet-water reservoir; the role of chlorides, Na, and K secondary. Many forms of water plants are found (the most important spp. are listed). The distribution of microorganisms in the irrigated sapropel bed is tabulated.—*CA*

Organization of Protective Areas for Water Supplies. W. Martens. *Gas- u. Wasserfach* (Ger.), 99:1283 ('58). The author discusses the importance of protection of the sources of water supplies and the planning of protective zones, with consideration of both present and future conditions. The relation of such planning to other uses of the land is discussed with special reference to legislation concerning land and water.—*WPA*

Provisions of the Law for Control of Water Resources. M. Witzel. *Wass. u. Boden* (Ger.), 9:343 ('57). A law for the control of water resources in Germany, replacing various differing laws of individual states, will come into force in 1959. It does not deal with such questions as personal ownership but with fundamental questions of far-reaching influence on the use and protection of waters. Every use of a source of water requires permission or approval with the exception of communal use, which is the affair of the individual states, and certain limited uses of surface and ground waters. Of special importance is the possibility of fixing protective areas for water supplies and the supplementing of ground water and for prevention of damaging runoff of storm water.—*WPA*

Multiple-Use Projects in Development of Water Resources. W. A. Dexheimer. *Proc. ASCE,* 84:IR3 ('58). The author reviews briefly the work of the Bureau of

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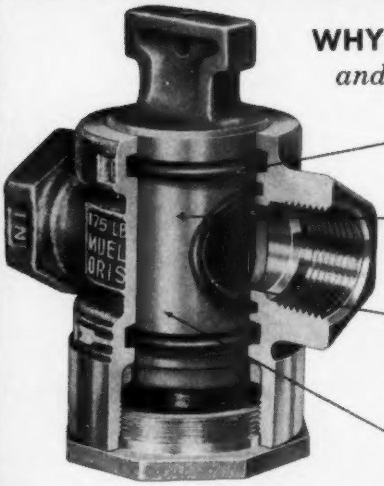

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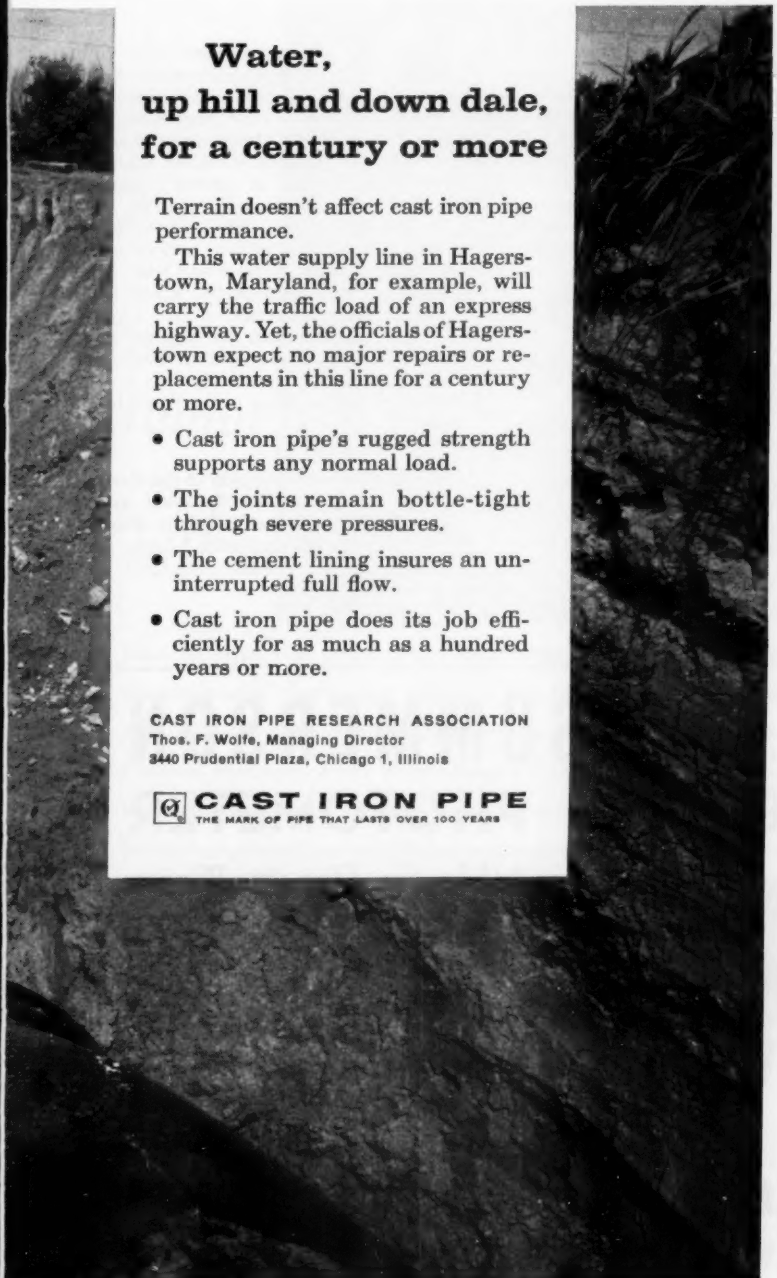
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Reclamation in planning the integration of water uses in the multiple-purpose development of river basins in the western states of the United States. In planning such projects, consideration must be paid to irrigation and flood control, hydroelectric power production, municipal and industrial water supply, navigation, fish and wildlife propagation, recreation, pollution prevention, sediment control, land drainage, and salinity control.—*WPA*

Hydrological and Hydrochemical Features of the Koval Lakes. K. M. Kurbangalieva. *Uchenye Zapiski Kazan. Gosudarst. Univ. im. V. I. Ul-yanova-Lenina, Obshcheuniv. Sbornik* (USSR), 117:246 ('57). The Koval lakes are located 25 km from Kazan city and consist of 3 basins: the Great Koval, the Medium Koval, and the Zimnitsa lakes. A remarkable difference in the O cont. of the surface and bottom waters of the Great Koval lake is observed in summer. The waters of the Medium Koval and the Zimnitsa lakes are almost constantly satd. with O, owing to an extended development of the plants. However, although the waters of the Koval lakes are in most cases satd. with O, free CO_2 is nearly always present in the summer period; its cont. increases from the surface to the bottom; it reaches a max. of 14.02 mg/l in the Medium Koval at the start of the channel, uniting this basin with the Zimnitsa lake. The surface waters affect only the temp. of the Great Koval lake. The hardness of the waters of the Koval lakes is low. The parameters of free CO_2 in relation to the intensity of the decompn. processes are significant, even in the summer period; this factor apparently has a neg. effect on the ichthyofauna of the Koval lakes. —*CA*

The Hydrological Condition of the Coastal Plain of Israel, and Its Relation to the Water Supplies of the Tel Aviv Region. Y. Peter & S. Wiegenfeld. *Tech. l-eau*

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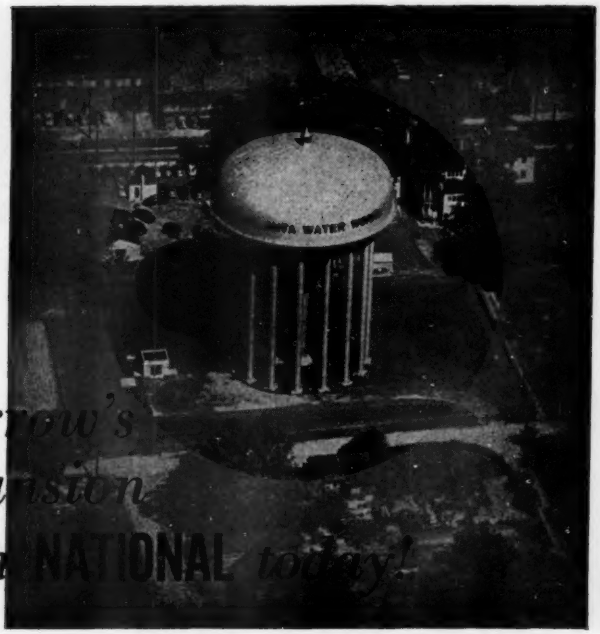

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(Brussels), 13:27 ('59). After detailed consideration of the hydrologic conditions existing in the central coastal plain of Israel, near Tel Aviv, their relationship to the water supplies of the Tel Aviv region is discussed. The problem of obtaining adequate domestic and industrial water supplies for Tel Aviv and the surrounding towns has become acute in recent years, when wells to the north of the town had to be closed down because of the infiltration of sea water. The possibility of obtaining supplies from ground water sources to the north, south, and east of Tel Aviv was considered, but finally rejected in favor of a scheme to abstract water from the River Yarkon at Rosh-Haayin. During the last 2 or 3 years, the possibility of providing an additional source of water for Tel Aviv and its environs from wells in the northern region was investigated, and this scheme is now being put into effect. Water is pumped from the wells along pipelines to 2 reservoirs, each having a capacity of 10,000 cu m, and from these it flows by gravity to the storage reservoirs of the town after chlorination. Diagrams showing the hydrologic conditions of the central plain, and a section through a well, and illustrations of the scheme being put into operation in the northern region, are included.—*WPA*

Hydrogeology and Cultivation of Land Near the Middle Portion of Tarim River, Sinkiang. M. Ch'en; K. Tu; & W. Wang. *Ti Chih K'o Hsueh,* 12:377 ('59). The ground water level is 5–9 m in depth from the surface. Coeff. of permeability ranges 10–20 m/24 hr, and hydraulic gradient is limited to 0.005–0.0001. Therefore, the velocity of ground water flow varies 0.75–1.5 cm/24 hr. The Tarim River water directly influences the diln. of mineralization of ground water. Areal influence of diln. of mineralization is about 1–5 mi, but the diln. decreases in degree away from the course of river. The HCO_3^--Na water type is confined to near the meandering zone, where the mineral cont. is 0.5 g/l. Farther away from

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the course, a HCO_3^--Na water type (0.5–1.0 g/l and 1–3 g/l) occurs; generally, a real influence within 0.5–1 mi carries a mineral cont. of 10–30 g/l or even greater than 30 g/l, and water is defined as Cl-Na type.—*CA*

Some Regularities in Hydrology and Geology of South Emba Artesian Basin. V. B. KOLPAKOV & D. A. DZHANGIR'YANTS. *Trudy Inst. Nefti, Akad. Nauk Kazakh. S.S.R.*, 3:61 ('59). The artesian basin comprises an area between Mugodzhar in the east, Emba-Kainar in the north, and South-Emba paleozoic elevation in the south. The border of the basin in the west is not clear (not. detd.). Water in this area is found in Permian, Triassic, Jurassic, Cretaceous, and Tertiary sediments. The sediments are chiefly sands and sandstones. The formation and behavior of ground waters are discussed. Three main water zones are distinguished. Detailed chem. characteristics of each water zone are given. The movement of ground waters in relation to salt domes as well as the relation of oil deposits to water behavior are discussed in detail.—*CA*

Effects of Forest Areas on Water Resources, and the Technique of Lysimetry. *Nature, Lond.*, 184:1184 ('59). The International Association of Scientific Hydrology held 2 symposia at Hannoversch-Munden, Germany, in September 1959: (1) *Water and Woodlands.* Papers presented at this symposium dealt with the influence of wooded areas on the elements of water balance. Experience and present knowledge in the hydrologic relationships of the forest were surveyed and discussed, and most contributors, with the exception of certain Russian authors, were prepared to accept a somewhat lower yield from a forested area as compared with areas under other vegetative covers. Following the symposium, an excursion was made to various forest catchment experiments in the area. (2) *Lysimeters.* Several papers presented gave descriptions of specific lysimeters, but in almost all of those described, there existed unmeasured variables. Several speakers emphasized the value of preliminary observations using cheap oil-drum lysimeters to det. potential evapotranspiration under "standard" conditions. An excursion was made to 3 lysimeter installations in the vicinity after the symposium.—*WPA*

US WATER SUPPLIES

Ground Water Supply of the Memphis Area. J. H. CRINER & C. A. ARMSTRONG. *US Geol. Survey, Circ.* No. 408 ('58). The area covered in the report is about 1,000 sq mi of Gulf Coastal Plain (the Miss. embayment). Only units of Eocene age and younger are discussed. Most of the H_2O used in the area is derived from the 500-ft sand of the Claiborne group and the 1,400-ft sand of the Wilcox group. In 1955, the avg daily pumpage of H_2O from all sources was 137 mil gal, 90% of which was obtained from the 500-ft sand. Water levels in wells penetrating the principal aquifers have declined continuously since pumping began; the aquifers are recharged mainly by pptn., and by percolation or leakage from adjacent rocks, but the Miss. river probably contributes some H_2O to the 500-ft sand and the terrace deposits. Quality of the H_2O from the 500- and 1,400-ft sands is very good, though it does contain appreciable quantities of Fe and CO_2; H_2O from terrace deposits is very hard.—*CA*

The Origin and Distribution of Phosphorus in Western Lake Erie. H. CURL JR. *Limnol. Oceanog.*, 4:66 ('59). The phosphate phosphorus (**I**) in western Lake Erie is contributed largely by the discharge of 2 rivers. The Detroit River contributes 405 metric tons per year of **I** at a concn. of 2.6γ, and the Maumee River contributes 125 tons at a concn. of 43 γ/l. **I** is lost to some extent by pptn. as ferric phosphate and adsorption on ferric hydroxide. Removal of fish by man accounts for an annual loss of 29 metric tons; 94 metric tons may be held in the form of phytoplankton.—*CA*

Distribution of Water in the United States as a Function of Hardness. L. O. LEENERTS. *J. Am. Oil Chemists' Soc.*, 36:200 ('59). A study was made of the hardness of the water throughout the United States in regard to its distribution by states and by total population. The purpose was (a) to det. the range of performance necessary for a soap or synthetic detergent product in order to be satisfactory to the majority of the pop. and (b) to det. the areas of distribution for products of varying performance characteristics in respect to water hardness. The study took into consideration municipal

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(*Continued from page 90 P&R*)

water treatment for the urban pop., the distribution of rural pop., and the distribution of home water softeners. The mean water hardness in the United States, ignoring the home softening units, was 136.6 ppm, with a standard deviation of 90.9 ppm. Twenty-one states, including the District of Columbia, were found to have a weighted avg hardness under 100 ppm. The hardest natural water is in a narrow belt covering the states of South Dakota, Iowa, Illinois, Indiana, and Ohio.—*CA*

Waste Water Role in Meeting Water Requirements. M. Bookman. *J. San. Eng. Div., Proc. ASCE,* 85:111 ('59). The water-deficient area in the southern portion of California faces the imminent need to supplement, by large quantities, the existing local and imported sources of water supply. This requires that consideration be given to the possibility of extending the use of existing sources of water by the reclamation of waste waters which would otherwise be discharged to the ocean. Presented is an evaluation of waste water reclamation and the relationship of the accomplishment of such projects to the forecast demands for new sources of water supply. The evaluation of the potential of waste water reclamation is based on the availability of quantities of waste waters of suitable quality which may be reclaimed at costs competitive with alternative sources of supplemental water. The markets for use of reclaimed water considered include direct uses for industry, agriculture, and recreation, and the indirect use through recharging the ground water supplies.—*PHEA*

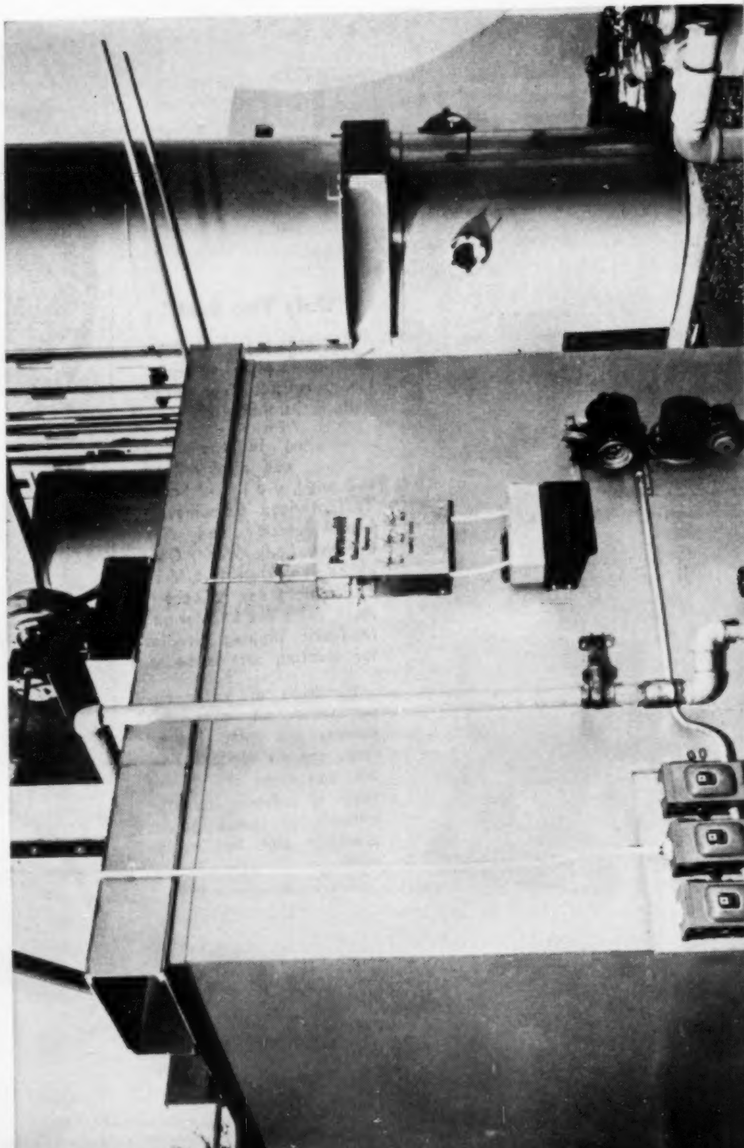
Water Use and Resources in the United States of America. R. L. Nace. *Water & Water Eng.,* 63:555 ('59). In a paper presented to the Texas Water Conservation Assn. at Dallas, Tex., in October 1959, the author stressed the need for improved water management in the USA, particularly in the state of Texas. National water resources are more than adequate, and records of water use indicate that much of the prospective increase in water demand could be met simply by more efficient use and distribution of the available water. The long-range responsibility of management is discussed, and the relation between the water program of USGS and general water management problems is considered.—*WPA*

Geology and Ground Water Resources of Gove County, Kan. W. G. Hodson & K. D. Wall. *Univ. Kansas Publ., State Geol. Survey Kansas Bul.,* No. 145, ('60). Chem. analyses of 52 ground waters are given. Most are moderately hard or very hard $CaHCO_3$ waters; some are high in sulfate. Most samples contained 0.5–1.4 ppm F. —*CA*

Geology and Ground Water Resources of Northwestern Polk County, Fla. H. G. Stewart Jr. *Florida Geol. Survey, Inform. Circ.* No. 23, 1 ('59). Anals., mostly partial, are given for waters from 16 wells, 1 spring, and 3 lakes. Most are moderately hard bicarbonate waters.—*CA*

Reconnaissance of the Ground Water Resources of Schoolcraft County, Mich. W. C. Sinclair. *Mich. Dept. Conservation, Geol. Survey Div., Progr. Rept.* No. 22, 1 ('59). This includes chem. anals. of 96 ground waters and 22 surface waters. The ground waters range from soft to very hard Ca-Mg bicarbonate waters; some from sandstones are very high in NaCl cont.—*CA*

FLUIDICS* AT WORK



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Not hogwash, but ham water, nevertheless, is to be the subject of public hearings in five major metropolitan areas in the near future to permit Secretary of Agriculture Freeman to weigh consumer opinion on whether or not he should suspend an order which now permits meat packers operating under federal inspection to add water to smoked hams and other pork products. We were about to suggest a strong protest of unfair competition by water utilities in the areas involved, but we wonder if, instead, we should consider the lesson in tie-in selling thereby to be learned. Of course, the butcher's rate schedule puts him at a considerable advantage, letting him charge well over $5 per gallon for the water in his ham, but perhaps a tie-in product or service might give us a better basis for establishing more sensible schedules of our own.

An immediate thought for a tie-in, of course, is other liquids. But, having learned from fluoridation how difficult it is to get people to agree on something which has no adequate alternative, we hate to think of the argument that would be aroused by the necessity

Joseph V. B. Wells (left), chief of the water resources division, USGS, was presented with the Distinguished Service Award of the Department of the Interior by Assistant Secretary John Kelly, at a ceremony held on Apr. 19. The award recognized more than 30 years of service in the fields of hydraulic engineering and hydrology. He was recently appointed by USGS as River Master of the Delaware River, a position that makes him responsible for the administration of provisions of a 1954 Supreme Court decree concerning water yields and uses, compilation of data, and observation of developments affecting the river.

(Continued on page 98 P&R)

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(Continued from page 96 P&R)

to select among Scotch, rye, bourbon, Irish, Canadian, gin, rum, and vodka. Then, too, more and more people are drinking them on the rocks these days, and there are even those who *will* take ginger ale.

A better avenue of approach, no doubt, is that of using the distribution system to distribute—if not ham, then perhaps sausage. The fact is, of course, that the distribution system is a channel through which every home in the community can be reached, and modern science would certainly have no trouble in providing selectivity in reaching the homes or even in providing a pressure-sealed delivery chamber before the meter, or, for larger deliveries, at curbside. Sealed in plastic, almost anything sizable could thus be dispatched to any water customer.

What an opportunity for tie-in sales then! With instant foods, for instance: "Just add some of what brought it to you!" With soaps: "Comes with water, goes with water!" We could merge with United Parcel, with Sears-Roebuck, with Western Union.

O.K. O.K. Hogwash!

The moon in June was the subject of a learned water supply dissertation at AWWA's Detroit Conference by Harry N. Lowe, deputy chief of the Missile & Space Office, Engineer Research & Development Laboratories, US Army Corps of Engineers, Fort Belvoir, Va. Meanwhile, from coeducational Cornell University has come word that Dr. Thomas Gold, director of the new center for radio physics and space research, has developed a new hypothesis concerning the availability of water on the moon. That Harry Lowe thinks man will have to make his own supply and that Tom Gold

(Continued on page 100 P&R)

This Month Years Ago

June 1886—The sixth annual AWWA meeting was held at Denver, Colo.

June 1911—The 31st AWWA annual meeting was held at Rochester, N.Y. . . .

The average spacing of hydrants in 63 US cities was reported as being one for each 558 ft of distribution main. A more rational basis for closely built-up areas was suggested by A. Hazen, that of average area per hydrant. . . .

A board of army officers appointed to examine results obtained by Major Darnall's model at Fort Myer, Va., for feeding liquid chlorine reported that "the apparatus is as efficient as purification by ozone or hypochlorite and is more reliable in operation than either . . . that it could be installed at a very low cost and that the cost of operation would be very slight." . . .

To serve the lower Detroit River section, Detroit financier R. P. Joy suggested the "construction of a canal, or aqueduct, from Port Huron to Lake Erie which would furnish the entire series of cities and villages with a wholesome and adequate water supply." . . .

At Sheboygan, Wis., it was reported that not a single death occurred from typhoid fever in January, February, March, April, or May.

June 1936—At the 56th annual AWWA Conference in Los Angeles, honorary memberships were presented to M. N. Baker, Upper Montclair, N. J., and Edward Bartow, professor of chemistry and chemical engineering at Iowa State University.

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believes that an extensive supply already exists there under a layer of ice and the reasons therefor are probably of great significance, but spring is here right now and we begin to wonder if it isn't man who is made of green cheese.

'Meter buggies' is the term used in Hayward, Calif., to describe the three-wheel vehicles (see cut below) used by the water department to save man-hours and costs on its meter-reading, collection, and maintenance operations.

City officials estimate that use of the vehicles, manufactured by Cushman Motors, Lincoln, Neb., will cut in half the time required to read meters.

Water pollution research will be the subject of an international conference to be held in London, England, in July 1962. The main US sponsor will be WPCF, in cooperation with other interested technical societies, including AWWA. Those interested in detailed information should contact the chairman of the steering committee, W. Wesley Eckenfelder, associate professor of civil engineering, Manhattan College, New York 71, N. Y.

Murray A. Wilson, consulting engineer of Salina, Kan., has been elected president of the National Society of Professional Engineers. He has served as president of the Kansas Engineering Society and the Kansas Section of ASCE. Other professional affiliations include AWWA, AICE, and the American Public Works Assn.

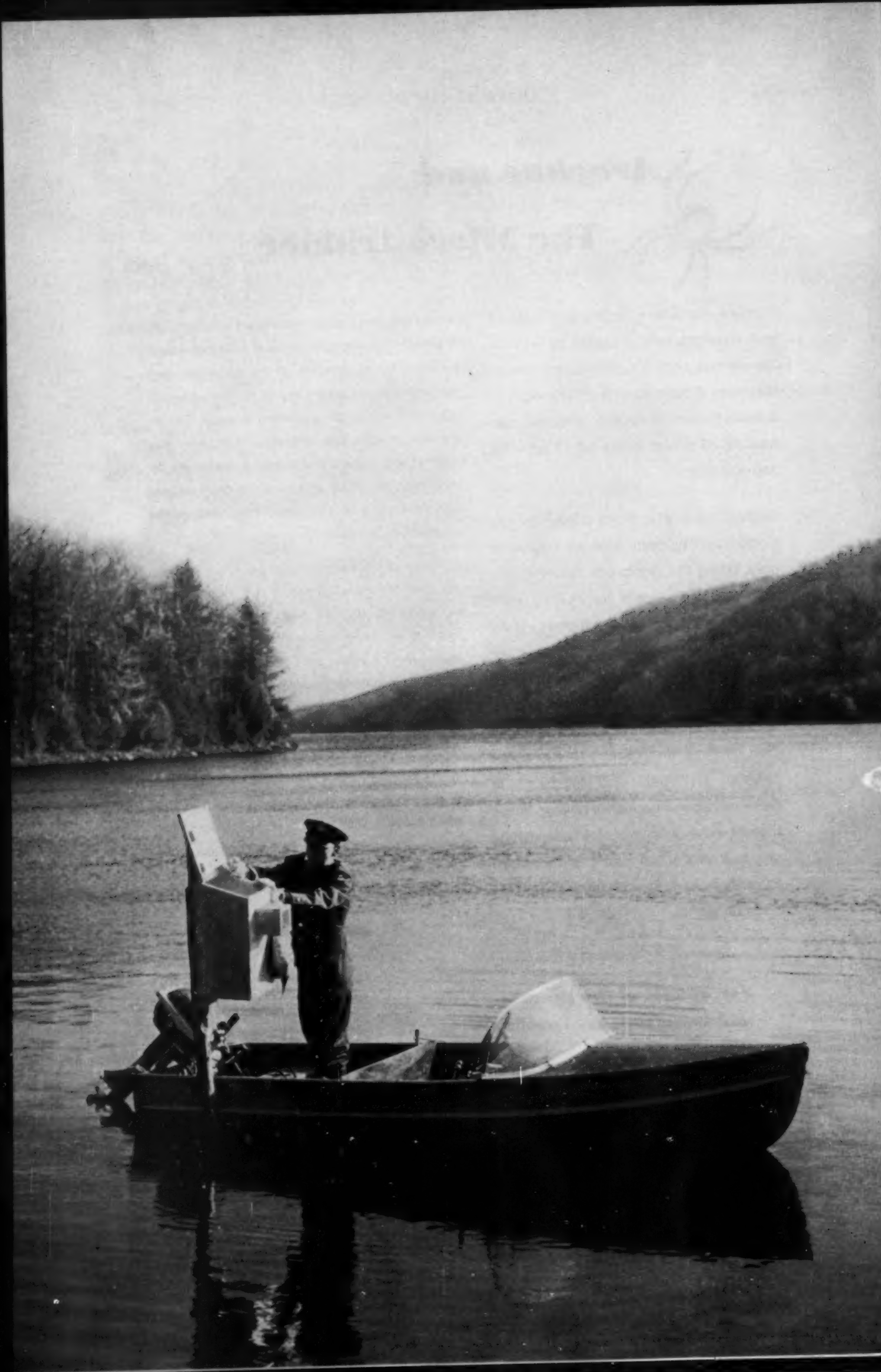
All's well that ends well was the story from three wells in the past month:

At Hamilton, N.Y., 4-year-old Barbara Linsley fell into a 24-ft well in an abandoned house. Her mother, wife of a Colgate professor of paleontology, sent the girl's 6-year-old brother running for help, then climbed down into the 3-ft-diameter well, pulled her daughter into her arms, and braced herself against the sides of the well until firemen came to extricate them some 20 minutes later—both without a scratch.

At Birmingham, Ala., it was 24-year-old Bobby Alvis who was trapped at the bottom of a 52-ft well when the concrete casing crumbled and fell on top of him. It took 6 hr to bring Bobby up, but he emerged in relatively good condition with only a mangled hand and some minor cuts to show for the experience.

And at Phoenix, Ariz., 7-year-old Harry Stage, son of a driller, fell into a 275-ft irrigation well, breaking both legs and his pelvis when he landed in the 250 ft of water at the bottom. Following his father's shouted instructions, Harry, who was unable to tread water because of his broken legs, used his

(*Continued on page 104 P&R*)



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arms against the sides of the small pipe to keep his head above water while the neighborhood was scoured for enough rope to reach him. Finally, a rope fashioned from all the lariats on the ranch was long enough. Following instructions he tied it under his arms and was slowly pulled out and put aboard a waiting ambulance.

All of which may serve to emphasize that wells are "attractive nuisances" that need to be accident proofed.

Gus Kempf, water superintendent at Ho-Ho-Kus, N.J., was recently honored by the community's mayor and city council for his 30 years of service to the community. He was presented with the special AWWA Willing Water plaque.

Rolf Eliassen will join the faculty of Stanford University on Sep. 1 as professor of civil engineering, a new position made possible through a training grant from USPHS. He is now acting head of the department of civil and sanitary engineering at Massachusetts Institute of Technology.

Proceedings of a recent conference on physiological aspects of water quality make available a variety of reports on the effects of minerals, trace elements, insecticides, and organic substances on potable water supplies. Copies of the proceedings are available on request from: Chief, Research and Training Grants Branch, Division of Water Supply and Pollution Control, USPHS, Washington 25, D.C.

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(Continued from page 104 P&R)

Plastic pipe that has been approved by the National Sanitation Foundation will now be accepted by the Federal Housing Administration for certain uses, including house service lines and potable cold-water services outside building foundation walls. Details of acceptable uses and requirements are outlined in the FHA bulletin No. UM-31.

'Fish Drinking Like Men' was the headline we liked best for a story from Bladnoch, Scotland, last month telling of a distillery workman who turned the wrong valve and permitted 5,000 fifths (153,900 nips by local count) of whiskey to escape into the river. Not the $28,000, but the pleasure thereby lost seems to have caused the major concern to the villagers, who apparently didn't get the word in time even to fish for the fun of it.

Pay up or shoot up were apparently the alternatives as Wade Berry of Jackson, Miss., saw them when he was told that his water had been shut off for nonpayment. So Wade appeared at the offices of the Hinds County Water Co. with his rifle in hand and, when the employees didn't move fast enough in lining up where he told them too, he fired a warning shot into the floor. Before he could make his point any more forcefully he was disarmed and trundled off to jail.

All the same, the city fathers of Mount Clemens, Mich., who have just finished giving a forceful reminder of a long overdue water bill for $16,000 to the US Air Force, are perhaps a little concerned. Of course, they haven't cut off the supply to Selfridge Air Force Base and of course the Air Force has continued to pay something for its water supply, on the basis of the old rate that was changed almost 3 years ago, but it must be a lot harder to hit *just* the floor from a few thousand feet up.

What price water—in the veins?

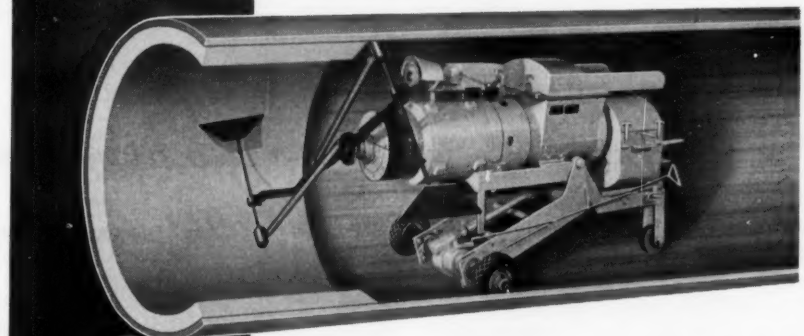
Earnest Boyce is retiring as chairman of the department of civil engineering at the University of Michigan. After Jul. 1 he will be available for assignments as a consulting engineer.

Beer, which has a history of at least 8,000 years and which has, according to its connoisseurs, done nothing but disimprove since the days of the first brewmasters—or at any rate since the Munchner-Dortmunder-Pilsener period —is about to take still another step in "the wrong direction." The step, which has been developed by the Miller Brewing Co. of Milwaukee and Union Carbide Development Co. of New York, involves the concentration of beer by freezing and removing its water (approximately 75 per cent of its volume) and then its reconstitution by the addition of water and carbon dioxide. The process is said to produce "a high quality product, substantially identical in taste and aroma to conventional beer." An application is now before the commissioner of internal revenue to adopt new regulations approving the process and permitting the brewers to label the product "beer," rather than "concentrated beer" or "reconstituted beer." Hearings have been scheduled for September 6.

In the industry a storm of protest is brewing. The process will discriminate against small brewers whose competitive advantage in local areas now depends upon freight costs, says the president of the Brewers Assn. of

(Continued on page 108 P&R)

A TOOL FOR RESTORING FLOW



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(Continued from page 106 P&R)

America. It will make hard-liquor drinkers of temperate drinkers says one brewmaster. It isn't beer, but an adulterated concentrate of beer that will make the public suspicious of all beer says another. It will accentuate the trend toward "monopoly and oligopoly" in the industry says the counsel of the brewery workers union.

Inasmuch as water does have an effect on the taste of beer—an effect that is advertised by at least two of the leading brewers—the process should mean that the same brand in different cities will have a difference in taste. But this could be as much an advantage as a disadvantage. We were a little disappointed that the process is too complicated to permit another "just add water," but since reconstitution is not, at least for now, to be a consumer problem, even that doesn't matter. We were rather surprised that the process did not include removal of the calories, at least as an optional procedure. But, when we get right down to it, we guess we're a connoisseur who can only judge this upcoming brew as Miller's Low Life!

Oscar G. Goldman has retired as superintendent of the San Francisco Water Dept. distribution division, after more than 47 years of service with the department. He is now general manager and chief engineer of the Master Leakfinding Corp., Evanston, Ill., in charge of their new division office in San Francisco.

A second course in sanitary engineering will be held at the Technological University, Delft, Netherlands, from October 1961 to July 1962. Arrangements have been made for qualified registrants from the US and Canada to obtain financial assistance from the Organization for European Economic Cooperation, one of the sponsors. Those interested in information should write the Netherlands Universities Foundation for International Cooperation, 27 Molenstraat, The Hague, Netherlands.

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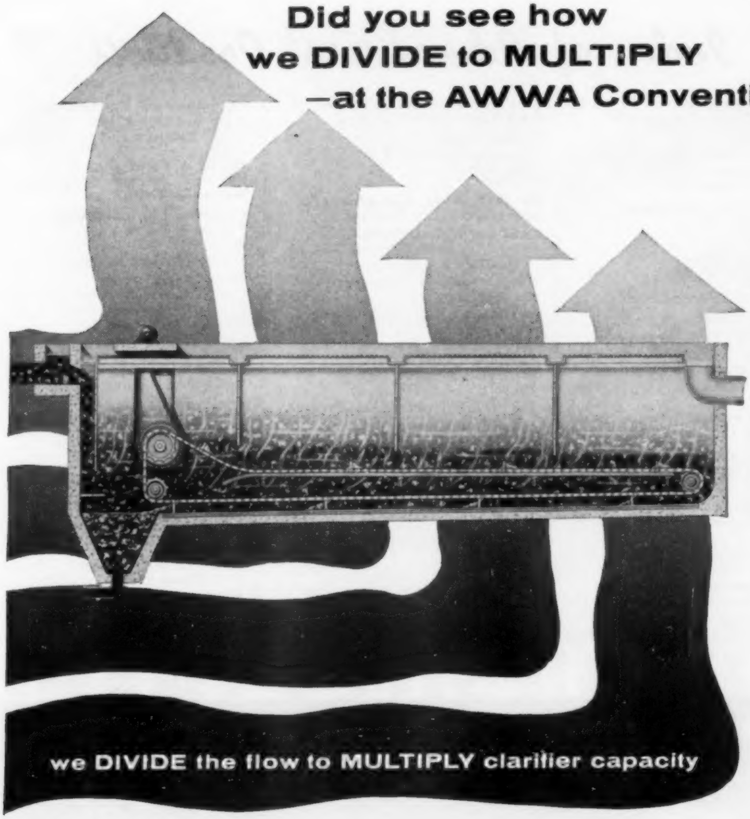

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Permutit Co.

Ferric Sulfate:
Tennessee Corp.

Filter Materials:
Anthracite Equipment Corp.
Carborundum Co.
General Filter Co.
Johns-Manville Corp.
Northern Gravel Co.
Permutit Co.
Stuart Corp.

Filters, incl. Feedwater:
B-I-F Industries, Inc.—Proportioneers
Dorr-Oliver Inc.
Eimco Corp., The
Permutit Co.
Roberts Filter Mfg. Co.
Ross Valve Mfg. Co.

Filtration Plant Equipment:
B-I-F Industries, Inc.—Builders
B-I-F Industries, Inc.—Omega
Chain Belt Co.
Eimco Corp., The
Filtration Equipment Corp.
General Filter Co.
Golden-Anderson Valve Specialty Co.
Hungerford & Terry, Inc.
Infilco Inc.
F. B. Leopold Co.
Permutit Co.
Roberts Filter Mfg. Co.
Simplex Valve & Meter Co.
Stuart Corp.
Wallace & Tiernan Inc.

Fittings, Copper Pipe:
Dresser Mfg. Div.
Hays Mfg. Co.
Mueller Co.

Fittings, Tees, Ells, etc.:
American Cast Iron Pipe Co.
James B. Clow & Sons
Dresser Mfg. Div.
M & H Valve & Fittings Co.
Morgan Steel Products, Inc.
Southern Pipe Div. of U.S. Industries
Trinity Valley Iron & Steel Co.
United States Pipe & Foundry Co.
R. D. Wood Co.

Flocculating Equipment:
Chain Belt Co.
Dorr-Oliver Inc.
Eimco Corp., The
General Filter Co.
Infilco Inc.
F. B. Leopold Co.
Permutit Co.
Stuart Corp.

Fluoride Chemicals:
American Agricultural Chemical Co.
General Chemical Div., Allied Chemical Corp.
Olin Mathieson Chemical Corp. (Mathieson Chemicals)
Ozark-Mahoning Co.
Tennessee Corp.

Fluoride Feeders:
B-I-F Industries, Inc.—Omega
B-I-F Industries, Inc.—Proportioneers
Fischer & Porter Co.
Wallace & Tiernan Co., Inc.

Furnaces:
Jos. G. Pollard Co., Inc.

Gages, Liquid Level:
Bailey Meter Co.
B-I-F Industries, Inc.—Builders
Fischer & Porter Co.
Simplex Valve & Meter Co.
Wallace & Tiernan Inc.

Gages, Loss of Head, Pressure of Vacuum, Rate of Flow, Sand Expansion:
Bailey Meter Co.
B-I-F Industries, Inc.—Builders
Fischer & Porter Co.
Foxboro Co.
Jos. G. Pollard Co., Inc.
Simplex Valve & Meter Co.
Wallace & Tiernan Inc.

Gasholders:
Bethlehem Steel Co.
Chicago Bridge & Iron Co.
Graver Tank & Mfg. Co.
Pittsburgh-Des Moines Steel Co.

Gaskets, Rubber Packing:
James B. Clow & Sons
Johns-Manville Corp.

Gates, Shear and Sluice:
Armco Drainage & Metal Products, Inc.
James B. Clow & Sons
Mueller Co.
R. D. Wood Co.

Gears, Speed Reducing:
DeLaval Steam Turbine Co.
Worthington Corp.

Glass Standards—Colorimetric Analysis Equipment:
Fischer & Porter Co.
Klett Mfg. Co.
Wallace & Tiernan Inc.

Goosenecks (with or without Corporation Stops):
James B. Clow & Sons
Mueller Co.
Southern Pipe Div. of U.S. Industries

Hydrants:
James B. Clow & Sons
Darling Valve & Mfg. Co.
M. Greenberg's Sons
Kennedy Valve Mfg. Co.
M & H Valve & Fittings Co.
Mueller Co.
A. P. Smith Mfg. Co.
R. D. Wood Co.

Hydrogen Ion Equipment:
Photovolt Corp.
Wallace & Tiernan Inc.

Hypochlorite; see Calcium Hypochlorite; Sodium Hypochlorite

Ion Exchange Materials:
General Filter Co.
Hungerford & Terry, Inc.
Nalco Chemical Co.
Permutit Co.
Roberts Filter Mfg. Co.
Rohm & Haas Co.

Iron, Pig:
Woodward Iron Co.

Iron Removal Plants:
American Well Works
General Filter Co.
Hungerford & Terry, Inc.
Permutit Co.
Roberts Filter Mfg. Co.
Walker Process Equipment, Inc.

Jointing Materials:
Johns-Manville Corp.
Keasbey & Mattison Co.
Leadite Co., Inc.

Joints, Mechanical, Pipe:
American Cast Iron Pipe Co.
James B. Clow & Sons
Dresser Mfg. Div.
Southern Pipe Div. of U.S. Industries
Trinity Valley Iron & Steel Co.
United States Pipe & Foundry Co.
R. D. Wood Co.

Leak Detectors:
Aqua Survey & Instrument Co.
Jos. G. Pollard Co., Inc.

Lime Slakers and Feeders:
B-I-F Industries, Inc.—Omega
Dorr-Oliver Inc.
General Filter Co.
Infilco Inc.
Permutit Co.
Wallace & Tiernan Inc.

Locators, Pipe & Valve Box:
Aqua Survey & Instrument Co.
W. S. Darley & Co.
Jos. G. Pollard Co., Inc.

Magnetic Dipping Needles:
Aqua Survey & Instrument Co.
W. S. Darley & Co.

Meter Boxes:
Ford Meter Box Co.
Rockwell Mfg. Co.

Meter Couplings and Yokes:
Badger Meter Mfg. Co.
Dresser Mfg. Div.
Ford Meter Box Co.
Gamon Meter Div., Worthington Corp.

Hays Mfg. Co.
Hersey-Sparling Meter Co.
Mueller Co.
Neptune Meter Co.
Rockwell Mfg. Co.

Meter Reading and Record Books:
Badger Meter Mfg. Co.

Meter Testers:
Badger Meter Mfg. Co.
Ford Meter Box Co.
Hersey-Sparling Meter Co.
Neptune Meter Co.
Rockwell Mfg. Co.

Meters, Domestic:
Badger Meter Mfg. Co.
Buffalo Meter Co.
Calmet Meter Div., Worthington Corp.
Gamon Meter Div., Worthington Corp.
Hersey-Sparling Meter Co.
Neptune Meter Co.
Rockwell Mfg. Co.

Meters, Filtration Plant, Pumping Station, Transmission Line:
Bailey Meter Co.
B-I-F Industries, Inc.—Builders
Fischer & Porter Co.
Simplex Valve & Meter Co.

Meters, Industrial, Commercial:
Badger Meter Mfg. Co.
Bailey Meter Co.
B-I-F Industries, Inc.—Builders
Buffalo Meter Co.
Calmet Meter Div., Worthington Corp.
Fischer & Porter Co.
Gamon Meter Div., Worthington Corp.
Hersey-Sparling Meter Co.
Neptune Meter Co.
Rockwell Mfg. Co.
Simplex Valve & Meter Co.

Mixing Equipment:
General Filter Co.
F. B. Leopold Co.

Motors, Electric:
Allis-Chalmers Mfg. Co.
Marathon Electric Mfg. Corp.
Worthington Corp.

Paints:
Inertol Co., Inc.
Koppers Co., Inc.
Plastics & Coal Chemicals Div., Allied Chemical Corp.

Pipe, Asbestos-Cement:
Atlas Asbestos Co. Ltd.
Johns-Manville Corp.
Keasbey & Mattison Co.

Pipe, Brass:
Anaconda American Brass Co.

Pipe, Cast Iron (and Fittings):
Alabama Pipe Co.
American Cast Iron Pipe Co.
James B. Clow & Sons
Trinity Valley Iron & Steel Co.
United States Pipe & Foundry Co.
R. D. Wood Co.

Pipe, Cement Lined:
American Cast Iron Pipe Co.
James B. Clow & Sons
Southern Pipe Div. of U.S. Industries
United States Pipe & Foundry Co.
R. D. Wood Co.

Pipe, Concrete:
American Pipe & Construction Co.
Lock Joint Pipe Co.
Vulcan Materials Co.

Pipe, Copper:
Anaconda American Brass Co.

Pipe, Plastic:
American Hard Rubber Co.
Keasby & Mattison Co.
Morgan Steel Products, Inc.
Orangeburg Mfg. Co., Div. of The Flintkote Co.

Pipe, Steel:
Armco Drainage & Metal Products, Inc.
Bethlehem Steel Co.
Morgan Steel Products, Inc.
Southern Pipe Div. of U.S. Industries

Pipe Cleaning Services:
Ace Pipe Cleaning, Inc.
Centriline Corp.
National Power Rodding Corp.
National Water Main Cleaning Co.
Robinson Pipe Cleaning Co.

Pipe Coatings and Linings:
American Cast Iron Pipe Co.
American Hard Rubber Co.
Centriline Corp.
Inertol Co., Inc.
Koppers Co., Inc.
Pipe Linings, Inc.
Plastics & Coal Chemicals Div., Allied Chemical Corp.
Reilly Tar & Chemical Corp.
Southern Pipe Div. of U.S. Industries

Pipe Cutters:
James B. Clow & Sons
Ellis & Ford Mfg. Co.
Pilot Mfg. Co.
Jos. G. Pollard Co., Inc.
A. P. Smith Mfg. Co.
Wachs, E. H., Co.
Wheeler Mfg. Corp.

Pipe Jointing Materials; see Jointing Materials

Pipe Locators; see Locators, Pipe

Plugs, Removable:
James B. Clow & Sons
Jos. G. Pollard Co., Inc.
A. P. Smith Mfg. Co.

Potassium Permanganate:
Carus Chemical Co.

Pressure Regulators:
Allis-Chalmers Mfg. Co.
Golden-Anderson Valve Specialty Co.
Mueller Co.
Ross Valve Mfg. Co.

Pumps, Boiler Feed:
DeLaval Steam Turbine Co.

Pumps, Centrifugal:
Allis-Chalmers Mfg. Co.
American Well Works
DeLaval Steam Turbine Co.
Peerless Pump Div.
C. H. Wheeler Mfg. Co.

Pumps, Chemical Feed:
B-I-F Industries, Inc.—Proportioneers
Fischer & Porter Co.
Precision Chemical Pump Corp.
Wallace & Tiernan Inc.

Pumps, Deep Well:
American Well Works
Fiese & Firstenberger
Layne & Bowler, Inc.
Peerless Pump Div.

Pumps, Diaphragm:
Dorr-Oliver Inc.
Wallace & Tiernan Inc.

Pumps, Hydrant:
W. S. Darley & Co.
Jos. G. Pollard Co., Inc.

Pumps, Hydraulic Booster:
Peerless Pump Div.
Ross Valve Mfg. Co.

Pumps, Sewage:
Allis-Chalmers Mfg. Co.
DeLaval Steam Turbine Co.
Peerless Pump Div.
C. H. Wheeler Mfg. Co.

Pumps, Sump:
DeLaval Steam Turbine Co.
Peerless Pump Div.
C. H. Wheeler Mfg. Co.

Pumps, Turbine:
Fiese & Firstenberger
Layne & Bowler, Inc.
Peerless Pump Div.

Recorders, Gas Density, CO_2, NH_3, SO_2, etc.:
Fischer & Porter Co.
Permutit Co.
Wallace & Tiernan Inc.

Recording Instruments:
Bailey Meter Co.
B-I-F Industries, Inc.—Builders
Fischer & Porter Co.
Simplex Valve & Meter Co.
Wallace & Tiernan Inc.

Reservoirs, Steel:
Bethlehem Steel Co.
Chicago Bridge & Iron Co.
Graver Tank & Mfg. Co.
Pittsburgh-Des Moines Steel Co.

Sand Expansion Gages; see Gages

Sleeves: see Clamps

Sleeves and Valves, Tapping:
James B. Clow & Sons
M & H Valve & Fittings Co.
Mueller Co.
Rensselaer Valve Co.
A. P. Smith Mfg. Co.

Sludge Blanket Equipment:
Eimco Corp., The
General Filter Co.
Infilco Inc.
Permutit Co.

Sodium Aluminate:
Nalco Chemical Co.

Sodium Chloride:
International Salt Co., Inc.

Sodium Fluoride:
American Agricultural Chemical Co.
General Chemical Div., Allied Chemical Corp.

Sodium Hexametaphosphate:
Calgon Co.

Sodium Hypochlorite:
Wallace & Tiernan Inc.

Sodium Silicate:
General Chemical Div., Allied Chemical Corp.
Philadelphia Quartz Co.

Sodium Silicofluoride:
American Agricultural Chemical Co.
General Chemical Div., Allied Chemical Corp.
Tennessee Corp.

Softeners:
Dorr-Oliver Inc.
General Filter Co.
Hungerford & Terry, Inc.
Permutit Co.
Roberts Filter Mfg. Co.
Walker Process Equipment, Inc.

Softening Chemicals and Compounds:
Calgon Co.
General Filter Co.
International Salt Co., Inc.
Nalco Chemical Co.
Permutit Co.
Tennessee Corp.

Standpipes, Steel:
Bethlehem Steel Co.
Chicago Bridge & Iron Co.
Graver Tank & Mfg. Co.
Pittsburgh-Des Moines Steel Co.

Steel Plate Construction:
Bethlehem Steel Co.
Chicago Bridge & Iron Co.
Graver Tank & Mfg. Co.
Morgan Steel Products, Inc.
Pittsburgh-Des Moines Steel Co.

Stops, Curb and Corporation:
Ford Meter Box Co.
Hays Mfg. Co.
Mueller Co.

Storage Tanks: see Tanks

Strainers, Suction:
James B. Clow & Sons
R. D. Wood Co.

Surface Wash Equipment:
Golden-Anderson Valve Specialty Co.
Permutit Co.

Swimming Pool Sterilization:
B-I-F Industries, Inc.—Builders
B-I-F Industries, Inc.—Omega
B-I-F Industries, Inc.—Proportioneers
Fischer & Porter Co.
Wallace & Tiernan Inc.

Tank Painting and Repair:
Koppers Co., Inc.
National Tank Maintenance Corp.

Tanks, Prestressed Concrete:
Preload Co., Inc.

Tanks, Steel:
Bethlehem Steel Co.
Chicago Bridge & Iron Co.
Graver Tank & Mfg. Co.
Morgan Steel Products, Inc.
Pittsburgh-Des Moines Steel Co.

Tapping-Drilling Machines:
Hays Mfg. Co.
Mueller Co.
A. P. Smith Mfg. Co.

Tapping Machines, Corp.:
Hays Mfg. Co.
Mueller Co.

Taste and Odor Removal:
B-I-F Industries, Inc.—Builders
B-I-F Industries, Inc.—Proportioneers
General Filter Co.
Industrial Chemical Sales Div.
Permutit Co.
Wallace & Tiernan Inc.

Turbidimetric Apparatus (For Turbidity and Sulfate Determinations):
Wallace & Tiernan Inc.

Turbines, Steam:
Allis-Chalmers Mfg. Co.
DeLaval Steam Turbine Co.

Valve Boxes:
James B. Clow & Sons
Ford Meter Box Co.
M & H Valve & Fittings Co.
Mueller Co.
Rockwell Mfg. Co.
A. P. Smith Mfg. Co.
Trinity Valley Iron & Steel Co.
R. D. Wood Co.

Valve-Inserting Machines:
Mueller Co.
A. P. Smith Mfg. Co.

Valve-Operating Units:
B-I-F Industries, Inc.
Filtration Equipment Corp.
Wachs, E. H., Co.
Wheeler, C. H., Mfg. Co.

Valves, Altitude:
Allis-Chalmers Mfg. Co., Hydraulic Div.
Golden-Anderson Valve Specialty Co.
Ross Valve Mfg. Co., Inc.

Valves, Butterfly, Check, Flap, Foot, Hose, Mud and Plug:
Allis-Chalmers Mfg. Co., Hydraulic Div.
B-I-F Industries, Inc.—Builders
James B. Clow & Sons
DeZurik Corp.
Kennedy Valve Mfg. Co.
M & H Valve & Fittings Co.
Mueller Co.
Pelton Div., Baldwin-Lima-Hamilton
Henry Pratt Cc.
Rockwell Mfg. Co.
R. D. Wood Co.

Valves, Detector Check:
Hersey-Sparling Meter Co.

Valves, Electrically Operated:
Allis-Chalmers Mfg. Co., Hydraulic Div.
B-I-F Industries, Inc.—Builders
James B. Clow & Sons
Darling Valve & Mfg. Co.
Golden-Anderson Valve Specialty Co.
Kennedy Valve Mfg. Co.
M & H Valve & Fittings Co.
Mueller Co.
Henry Pratt Co.
Rockwell Mfg. Co.
A. P. Smith Mfg. Co.

Valves, Float:
James B. Clow & Sons
Golden-Anderson Valve Specialty Co.
Henry Pratt Co.
Rockwell Mfg. Co.
Ross Valve Mfg. Co., Inc.

Valves, Gate:
James B. Clow & Sons
Darling Valve & Mfg. Co.
Dresser Mfg. Div.
Kennedy Valve Mfg. Co.
M & H Valve & Fittings Co.
Mueller Co.
A. P. Smith Mfg. Co.
R. D. Wood Co.

Valves, Hydraulically Operated:
Allis-Chalmers Mfg. Co., Hydraulic Div.
B-I-F Industries, Inc.—Builders
James B. Clow & Sons
Darling Valve & Mfg. Co.
DeZurik Corp.
Golden-Anderson Valve Specialty Co.
Kennedy Valve Mfg. Co.
F. B. Leopold Co.
M & H Valve & Fittings Co.
Mueller Co.
Pelton Div., Baldwin-Lima-Hamilton
Henry Pratt Co.
Rockwell Mfg. Co.
A. P. Smith Mfg. Co.
R. D. Wood Co.

Valves, Large Diameter:
Allis-Chalmers Mfg. Co., Hydraulic Div.
James B. Clow & Sons
Darling Valve & Mfg. Co.
Golden-Anderson Valve Specialty Co.
Kennedy Valve Mfg. Co.
M & H Valve & Fittings Co.
Mueller Co.
Pelton Div., Baldwin-Lima-Hamilton
Henry Pratt Co.
Rockwell Mfg. Co.
A. P. Smith Mfg. Co.
R. D. Wood Co.

Valves, Regulating:
Allis-Chalmers Mfg. Co., Hydraulic Div.
DeZurik Corp.
Golden-Anderson Valve Specialty Co.
Mueller Co.
Henry Pratt Co.
Rockwell Mfg. Co.
Ross Valve Mfg. Co.

Valves, Swing Check:
James B. Clow & Sons
Darling Valve & Mfg. Co.
Golden-Anderson Valve Specialty Co
M & H Valve & Fittings Co.
Mueller Co.
Rockwell Mfg. Co.
A. P. Smith Mfg. Co.
R. D. Wood Co.

Venturi Tubes:
B-I-F Industries, Inc.—Builders
Rockwell Mfg. Co.
Simplex Valve & Meter Co.

Waterproofing:
Inertol Co., Inc.
Koppers Co., Inc.
Plastics & Coal Chemicals Div., Allied Chemical Corp.

Water Softening Plants; see Softeners

Water Supply Contractors:
Layne & Bowler, Inc.

Water Testing Apparatus:
LaMotte Chem. Products Co.
Wallace & Tiernan Inc.

Water Treatment Plants:
American Well Works
Chain Belt Co.
Chicago Bridge & Iron Co.
Dorr-Oliver Inc.
Eimco Corp., The
General Filter Co.
Hungerford & Terry, Inc.
Infilco Inc.
Permutit Co.
Pittsburgh-Des Moines Steel Co.
Roberts Filter Mfg. Co.
Walker Process Equipment, Inc.
Wallace & Tiernan Inc.

Well Drilling Contractors:
Layne & Bowler, Inc.

Well Reconditioning and Formation Testing:
Halliburton Co.
Layne & Bowler, Inc.

Wrenches, Ratchet:
Dresser Mfg. Div.

Zeolite: see Ion Exchange Materials

A complete Buyers' Guide to all water works products and services offered by AWWA Associate Members appears in the 1959 AWWA Directory.